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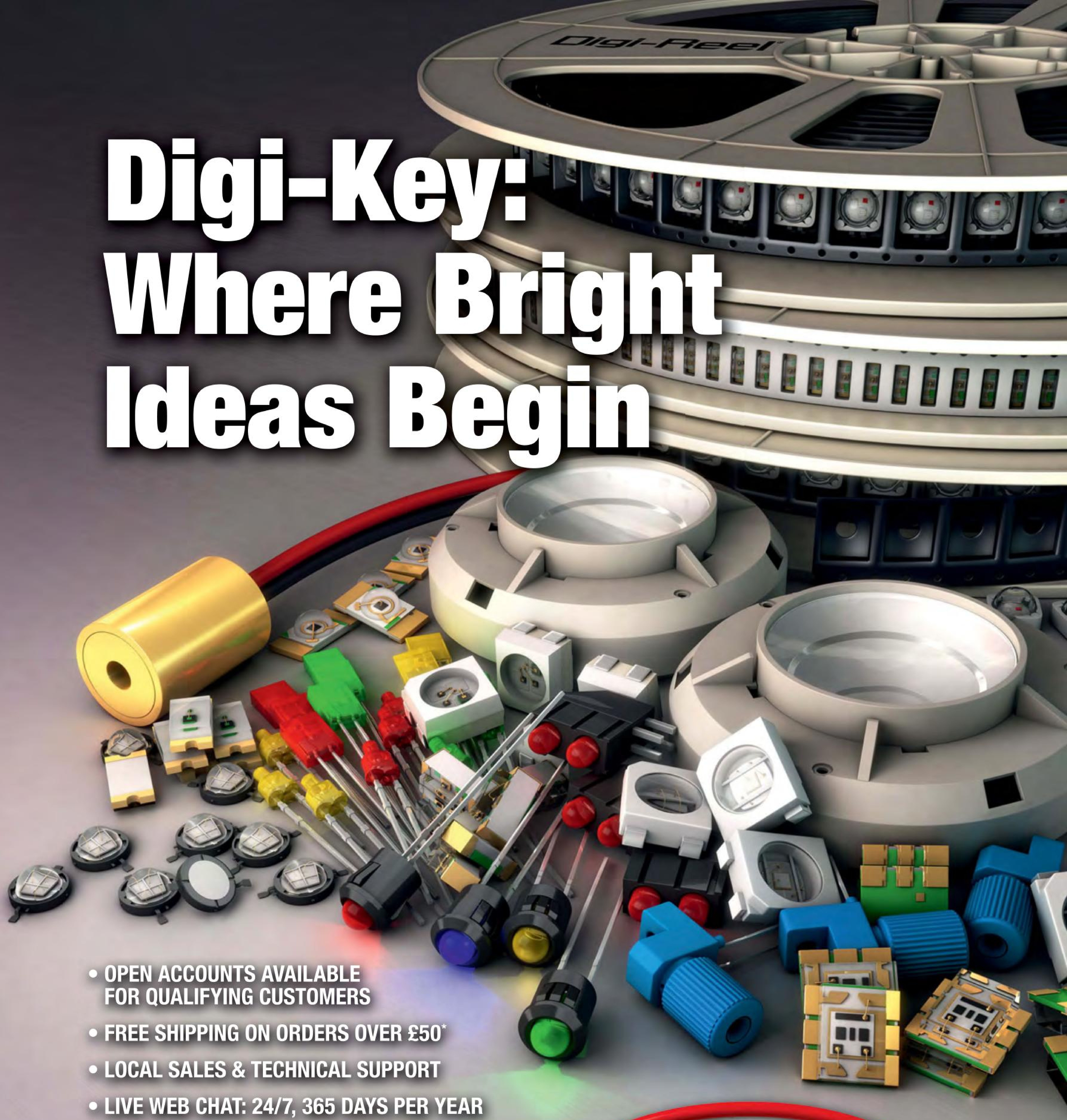

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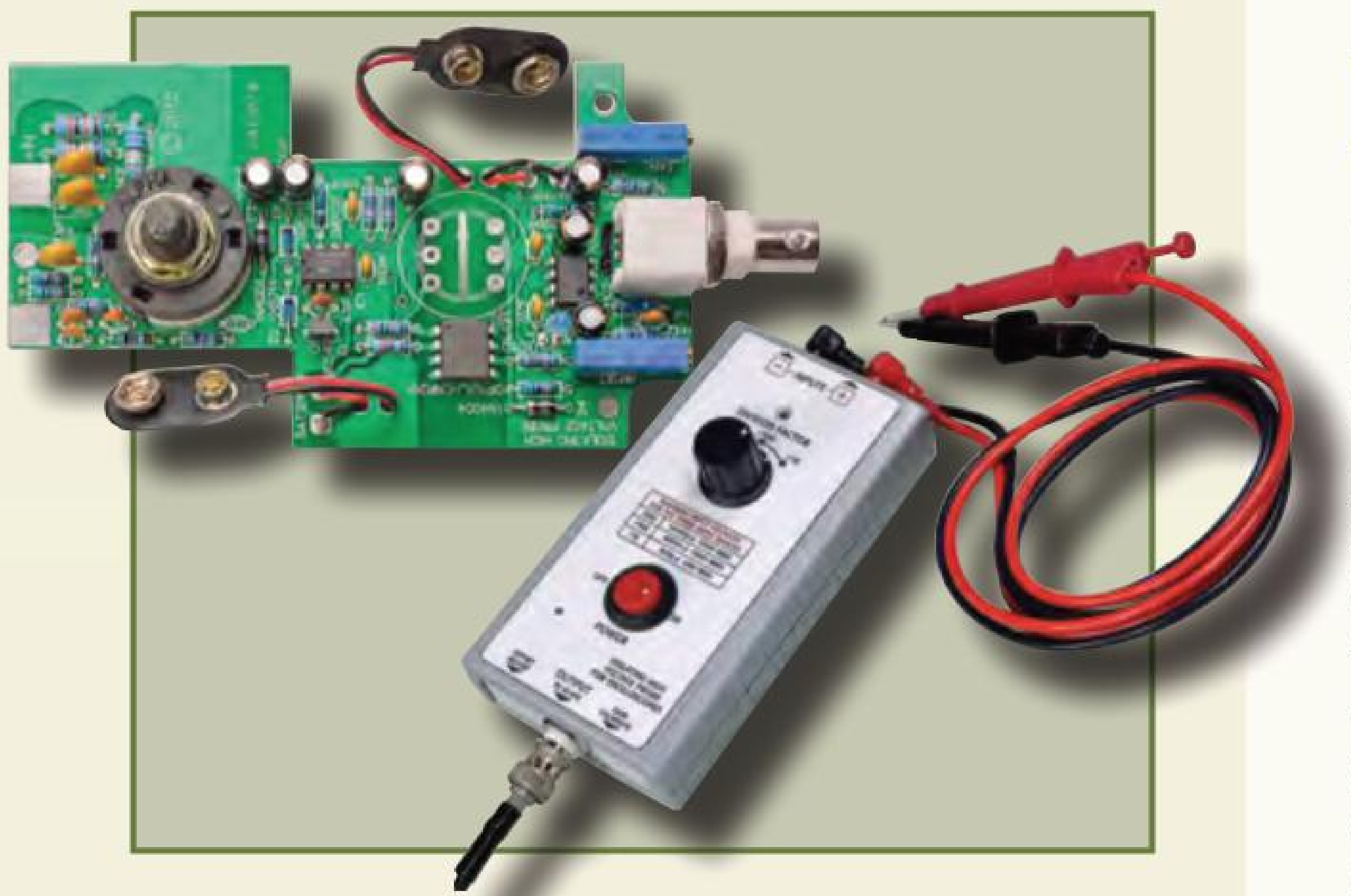

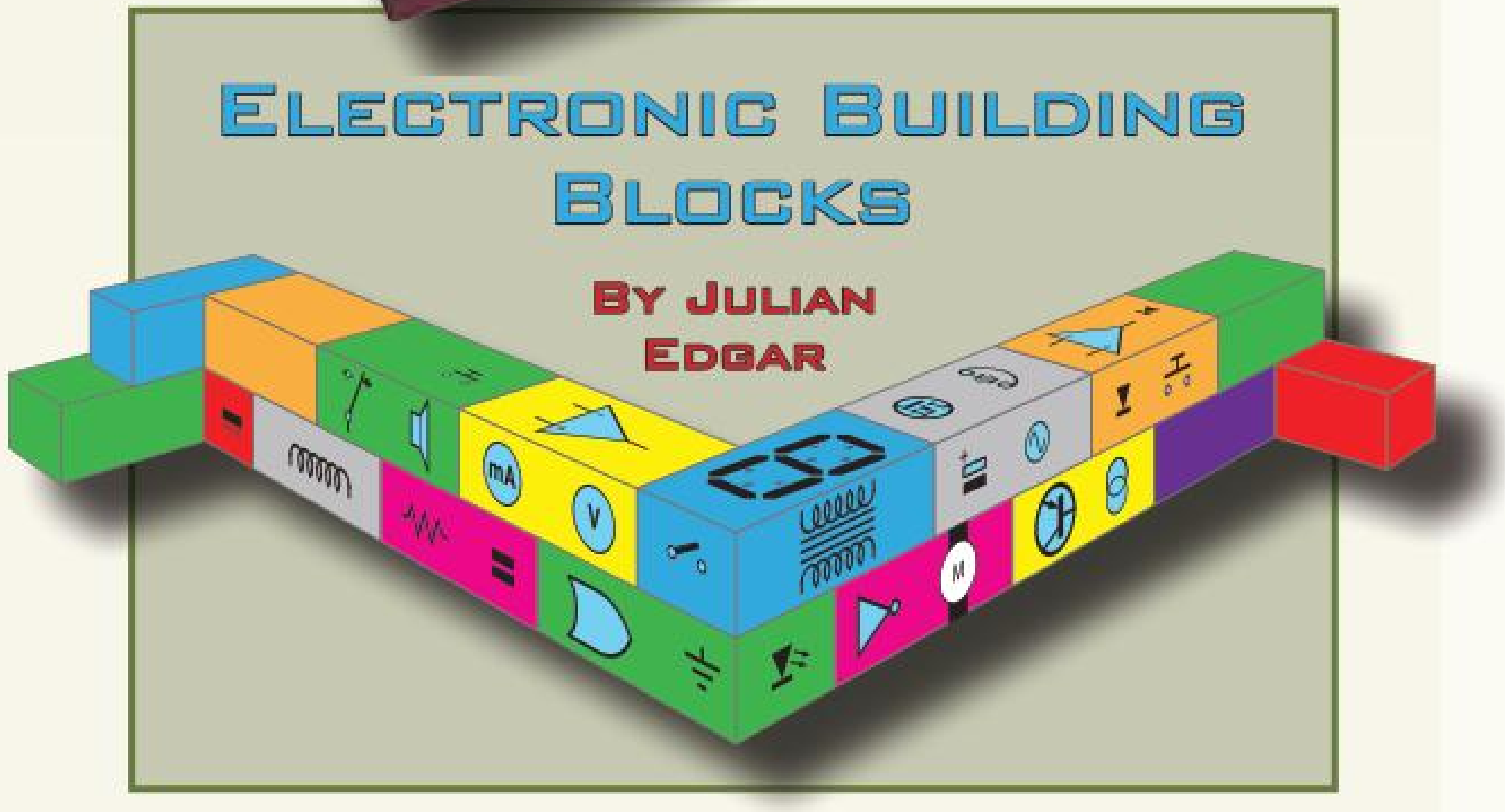

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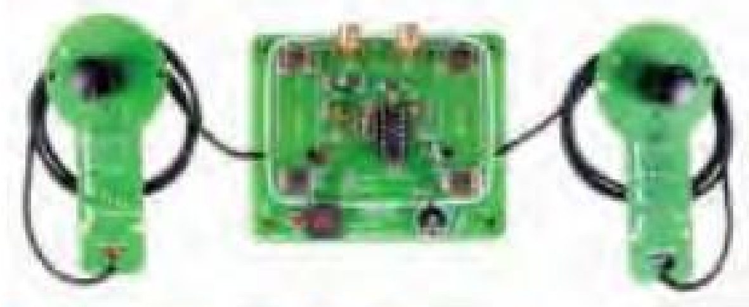

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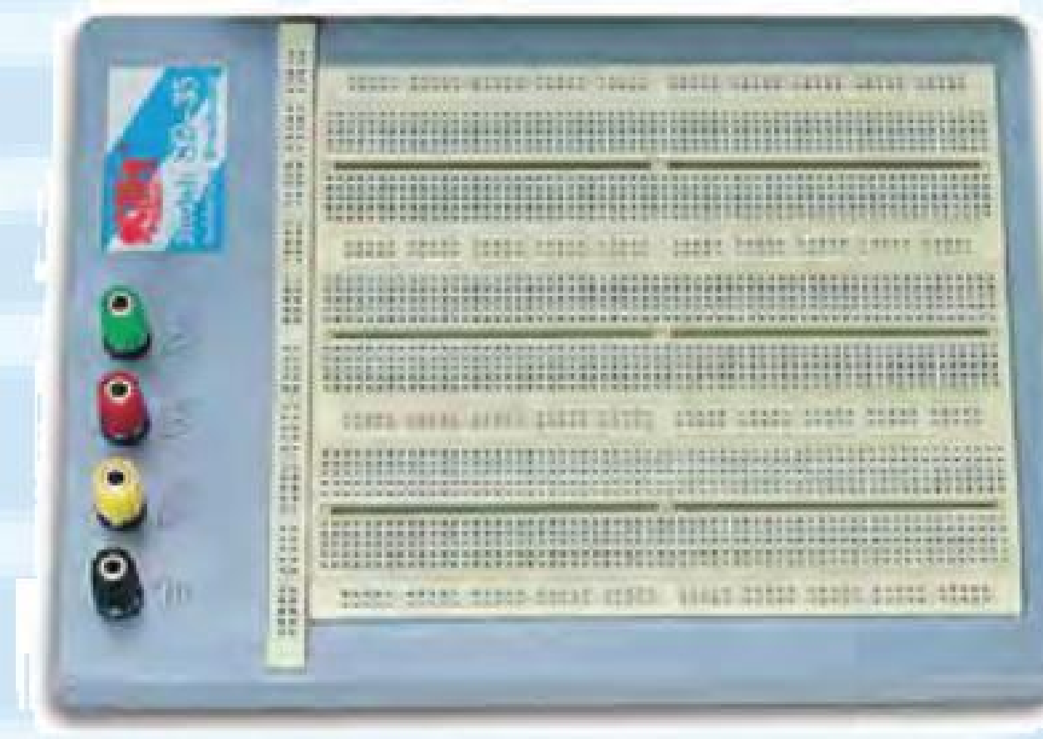

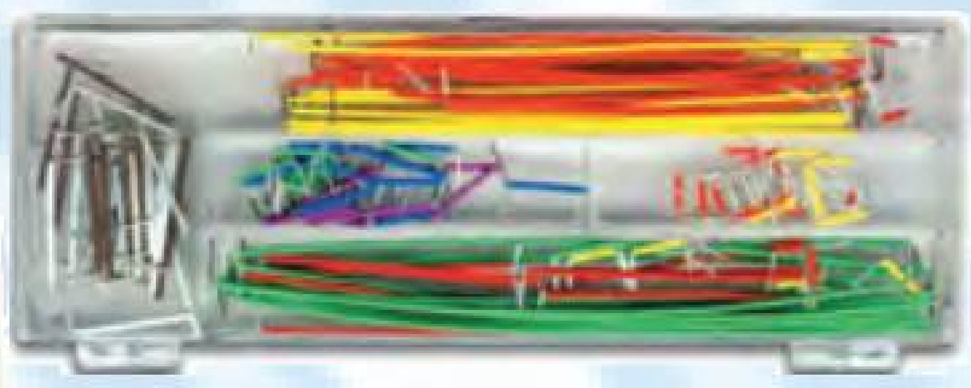

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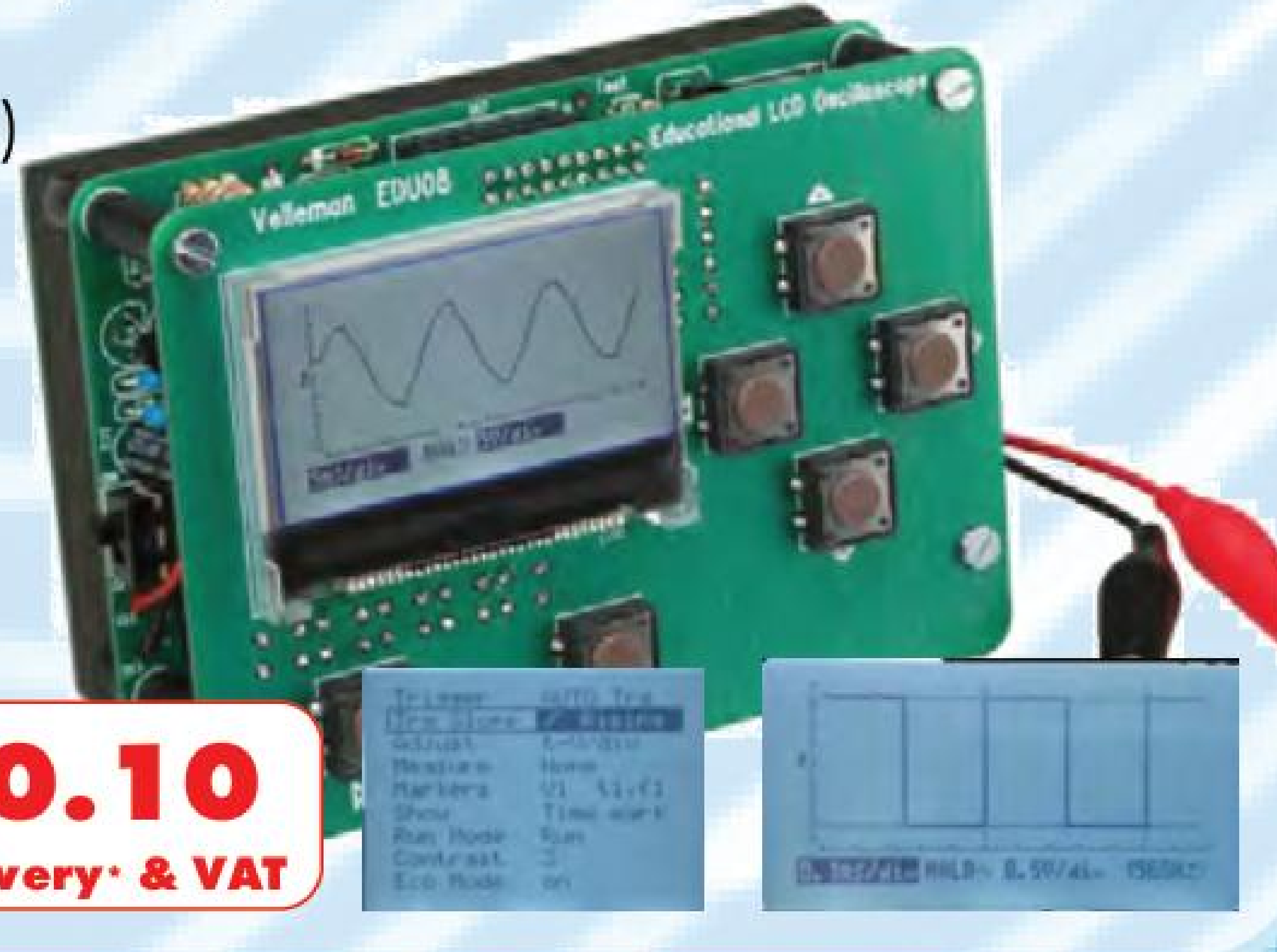
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General Manager:	FAY KEARN
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EVERYDAY PRACTICAL ELECTRONICS

Currawong amplifier

I hope you have been enjoying the series on the *Currawong Valve Amplifier* – do read the final installment in this issue, which includes a very handy remote control for the volume. On the same topic, a reader has alerted us to supply issues with the comprehensive kit from Altronics. The website currently says 'out of stock', so we contacted Altronics and got the following positive response: 'I can confirm we will be doing another run of the kit, but not until early 2016 due to problems with transformer availability with our supplier. Your readers should be able to place a backorder with us until stock arrives if they wish to do so.' So, hopefully, a little patience will be rewarded.

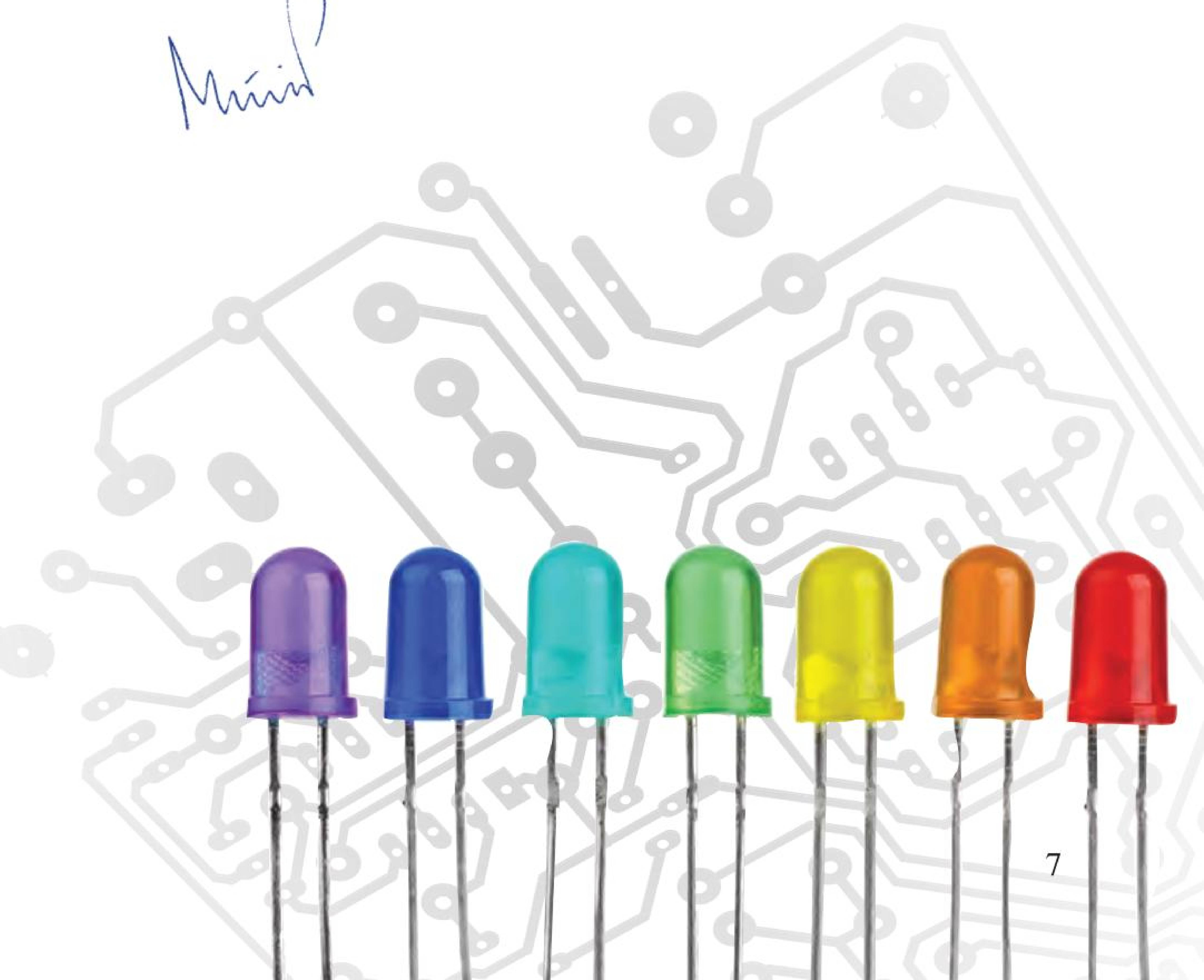
Snake impedance

I have mentioned the 'webcomic' **xkcd.com** before – it's good fun, free and nice to see something online that manages to combine both science and technology with subtle humour. This week's strip amused me and will you too I hope: **http://xkcd.com/1604** – do note that with xkcd you always get a little 'extra' if you let you mouse hover over the comic.

Season's greetings

In the last issue – December 2015 – I looked forward to 2016 and thanked our loyal and hardworking contributors. Such are the vagaries of the publishing year that the January issue actually comes out before Christmas, so in this issue I would like to sign off with a big 'Thank You' to you, our loyal readers. Everyone at Wimborne Publishing truly appreciates your support for *EPE*, your questions, letters, emails, tips, ideas and of course your enormous contribution to our online forum, *Chat Zone*, all of which help us to produce the best magazine we can.

Now, all that's left for me to do is wish you all a very Happy Christmas and an enjoyable, electronics-filled New Year.



NEWS

A roundup of the latest Everyday News from the world of electronics

4K TV rush to market compromises standards – *report by Barry Fox*

'After listening to the day's speakers, I have to tell you I am scared' admitted Howard Saycell, CEO, RETRA – The Radio, Electrical and Television Retailers' Association – the UK CE dealers' trade body. He was speaking at the end of the day-long Ultra HD Conference sponsored by satellite operator SES Astra and held at the HQ of the UK's Digital Television Group.

4K not futureproof

'I am scared for retailers, customers and investors. When our customers buy a 4K Ultra HD set they think they are getting something futureproof. But now I know they are not.

'I run RETRA's legal help line and we tell dealers and manufacturers to treat customers fairly' Saycell continued. 'Everything on their websites must be laid out clearly to say what goods will do. I see here the prospect of class actions. We don't want to be like VW. We have a massive communications job.'

During the day-long conference a succession of high-level industry speakers had detailed the lack of standards for 4K UHD and the high volumes of 4K UHD product already being sold without anyone having any idea of how it will work with future products and services.

Nick Simon of market analysts GfK, reported that the UK now leads Europe in UHD, with half a million sets sold three quarters of the way through the year. In 2017 he expects sales to reach three million.

'With HD TV it was all sorted out before anyone had the chance to buy' said Andy Quested, Head of Technology, BBC. 'With UHD, it is all happening incredibly fast – too fast – and we are washing our dirty laundry in public'.

Stephan Heimbecher, Head of Innovations & Standards, Sky Deutschland reminded that his channel had been working on 4K or 'Beyond HD' since 2011, and was now able to handle live UHD, end to end. 'In 2011 we didn't think standards would take this long, and they look likely to keep us busy for a few more years. There are a hundred and one things to be done, and the consumer is already confused.'

ASA consumer 'support'?

So who is protecting the consumer from this confusion? Certainly not the UK ASA (Advertising Standards Authority).

4K Ultra HD TV offers the potential for stunning images, but have the standards been thought through properly?

In mid-2014, Japanese company Sharp claimed its new range of TV sets was 'the only Full High-Definition TV on the market that plays 4K content through HDMI, playing both native 4K content and also upscaling a Full High-Definition source or lower-resolution source to 4K'. Sharp also claimed to 'display 2.5 times as many sub-pixels for a higher than Full HD resolution'.

I queried the claims but got no useful answers from Sharp, so requested the ASA to ask Sharp. I argued that only a skilled engineer can be expected to understand and evaluate the technicalities of colour sub-pixellation.

It took a full 16 months of behind-the-scenes argument with the ASA before Sharp finally withdrew its web-page promotion. During that time, the promotion continued and I was gagged by confidentiality demands from the ASA.

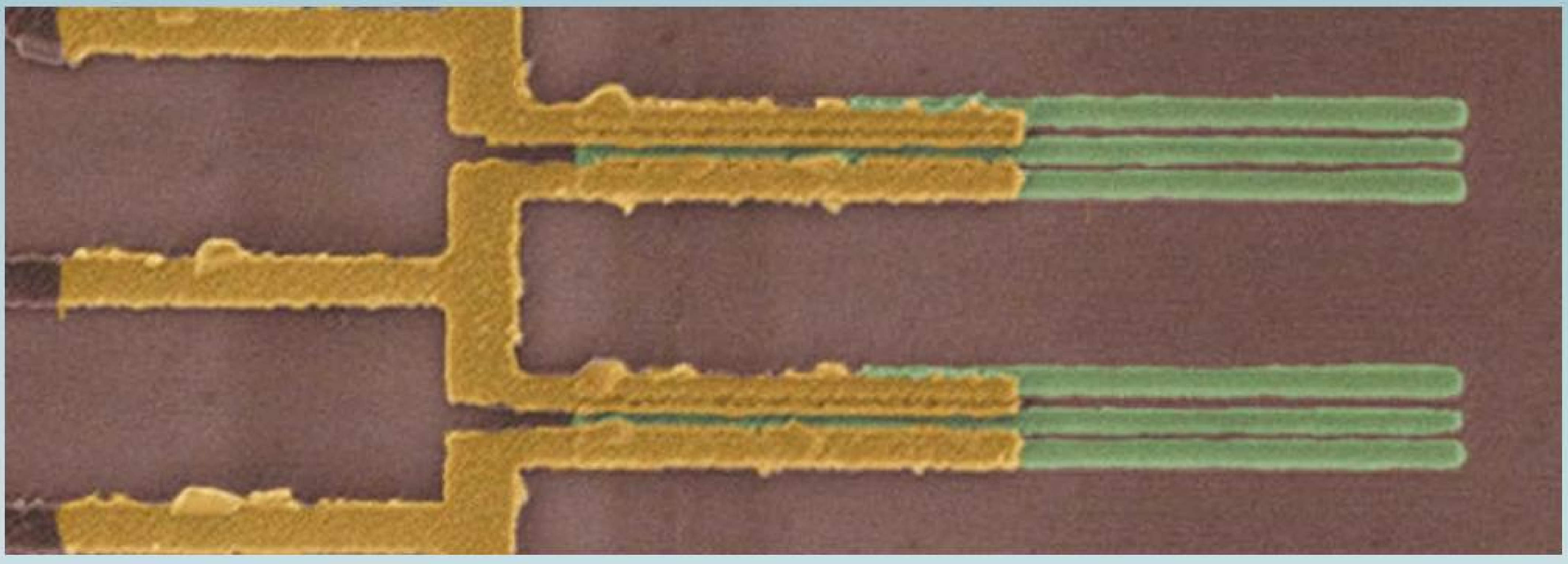
And when the ASA finally published a note on Sharp's climb-down it referred only to an 'informally resolved case' concerning 'leisure' and did not identify the advert content, or period of time the case was under consideration – see: **www.asa.org.uk/Rulings/Adjudications.aspx?date=30/09/2015#2**

Poor consumer protection

ASA Chief Executive Guy Parker says the length of time taken to resolve the case was 'unusual… but the claims related to technical matters, and we had to give them careful consideration, including consulting with third parties. The case got to the point where, having updated our recommendation, we were faced with the option of entering into another round of correspondence with the advertiser, with the attendant use of resources and the possibility of the case taking even longer, or of accepting the assurance they had offered that the claims would not be repeated and closing it. On balance, and taking into account the nature of the ad and its impact, we decided on the latter.'

Because the notice posted by the ASA does not identify the subject as a 2K/4K TV, any member of the public who bought a TV on the strength of the offending adverts and has become disappointed in their purchase cannot now know that those adverts were withdrawn after a complaint – or know how long it took to resolve. So class actions will be harder to bring.

IBM breakthrough with carbon nanotube transistors



IBM's nanotube transistors – IBM Research

IBM Research has announced a major engineering breakthrough that could accelerate carbon nanotubes replacing silicon transistors to power future computing technologies.

IBM scientists have demonstrated a new way to shrink transistor contacts without reducing performance of carbon nanotube devices, opening a pathway to dramatically faster, smaller and more powerful computer chips beyond the capabilities of traditional semiconductors.

Beating the silicon bottleneck

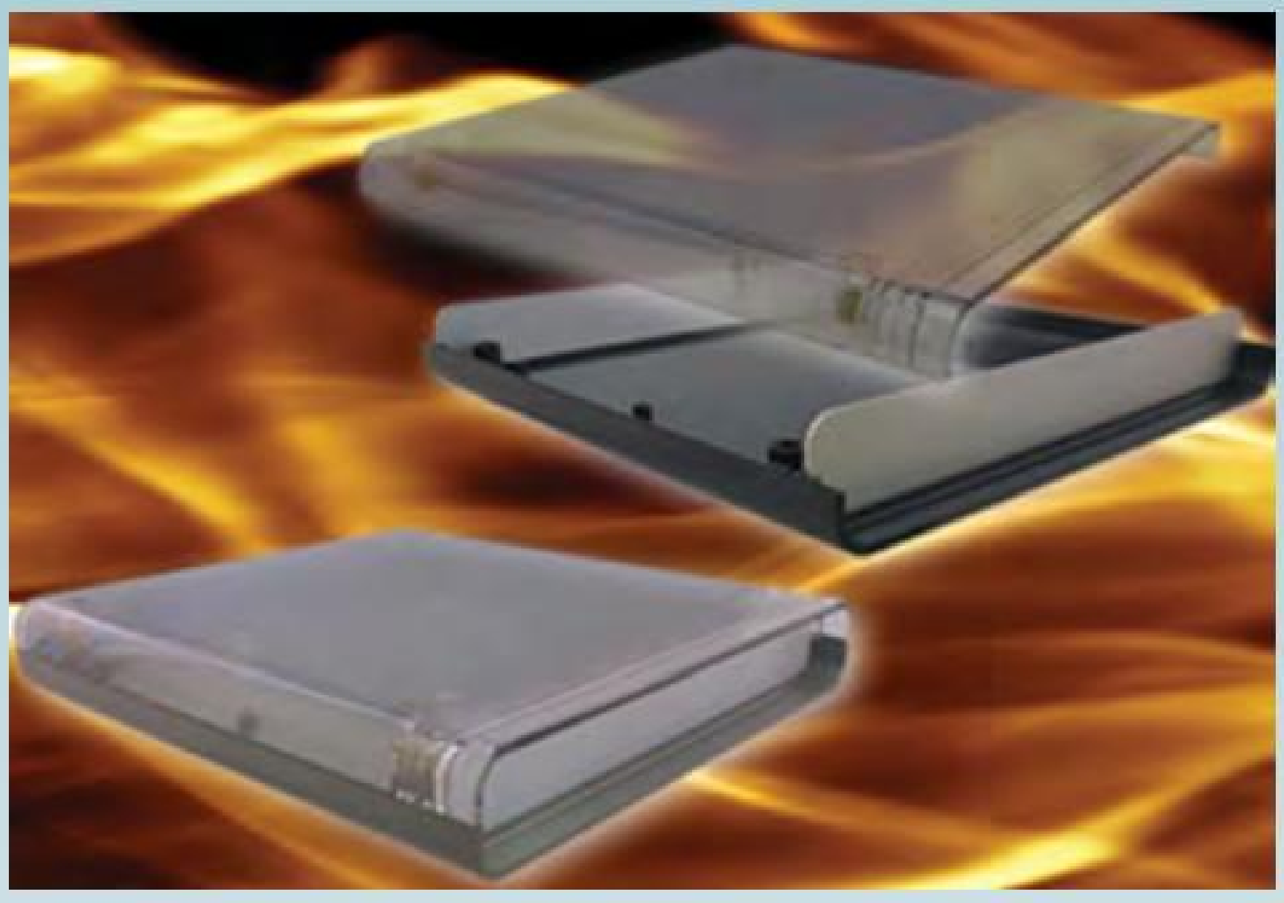
IBM's breakthrough overcomes a major hurdle that silicon and any semiconductor transistor technologies face when scaling down. In any transistor, two things scale: the channel and its two contacts. As devices become smaller, increased contact resistance for carbon nanotubes has hindered performance gains – until now. IBM researchers had to forego traditional contact schemes and invented a metallurgical process akin to microscopic welding that chemically binds the metal atoms to the carbon atoms at the ends of nanotubes. This 'end-bonded contact scheme' allows the contacts to be shrunken down to below 10 nanometers without deteriorating performance of the carbon nanotube devices. These results could overcome contact resistance challenges all the way to the 1.8 nanometer node – four technology generations away.

Carbon nanotube chips could greatly improve the capabilities of high-performance computers, enabling 'big data' to be analysed faster, increasing the power and battery life of mobile devices and the Internet of Things, and allowing cloud data centers to deliver services more efficiently and economically.

Silicon transistors have been made smaller year after year, but they are approaching physical limits. With Moore's Law running out of steam, shrinking the size of the transistor – including the channels and contacts – without compromising performance has been a vexing challenge troubling researchers for decades.

IBM has previously shown that carbon nanotube transistors can operate as excellent switches at channel dimensions of less than ten nanometers – the equivalent to 10,000 times thinner than a strand of human hair and less than half the size of today's leading silicon technology. IBM's new contact approach overcomes the other major hurdle in incorporating carbon nanotubes into semiconductor devices, which could result in smaller chips with greater performance and lower power consumption.

Vero Technologies' stylish new enclosure



Vero Technologies has launched a new range of SoftStyle modular moulded enclosures made from a flame-retardant polycarbonate, which allows translucent mouldings and offers better UV stability than ABS or other materials. The top features a clear frosted finish, so internal indicators are easily visible. The plan size is 220 wide × 230mm deep and there are three standard heights: 35, 70 and 105mm, achieved with one or two 35mm high side infill panels.

No visible fixings ensure a clean uncluttered appearance. Six PCB standoffs are provided in both top and base, and brass inserts and machine screws enable repeated openings and closings.

Details from: **www.verotl.com/en/category/polycarbonate-enclosures**

Bye bye Betamax

Bowing – somewhat late in the day – to the inevitable, Sony is to stop selling Betamax video tapes. Sony launched Betamax before its arch rival JVC produced the VHS format, but failed to capture the market. Despite being acknowledged as a superior product it was relegated to the much smaller professional arena, becoming a byword for technical superiority undermined by inferior business strategy.

New colours brighten Hammond's enclosures

New red or blue anodised finishes for the 1455 family of extruded aluminium instrument cases from Hammond Electronics will allow designers and hobbyists to make their products stand out from the crowd without going to the time and expense of specifying custom finishes.

The extensive 1455 family consists of 22 sizes from the compact 60 × 45 × 25mm to the largest 220 × 165 × 52mm size. All sizes are now available in a durable red or blue anodised finish in addition to the original clear and black anodised options.

The 1455 is designed to house PCBs mounted horizontally into internal slots in the body of the case, or as an enclosure for any small electronic, electrical or pneumatic instrument. All sizes, apart from the smallest ones have a removable slide cover on the case body to allow access to the PCB when it is in situ. The 14 largest sizes are designed to accept a standard 100 × 160mm or 100 × 220mm Eurocard. The entire 1455 range is supplied complete with fixings and self-adhesive rubber feet; flange brackets that enable the unit to be mounted directly to a shelf or wall are also available as an optional accessory. For more details: **www.hammondmfg.com/1455.htm**

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- Instrumentation amps

LED Lighting

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TechnoTalk

Many new cars are hopelessly unsafe!

Mark Nelson

With the advent of the 'connected car', new models are a prime target for hackers. Chips that falsify emissions suddenly look trivial against what terrorist and ransom merchants can do to your next set of wheels, as Mark Nelson now explains.

WHY ARE NEW CARS LIKE THE smart utility meters in your home or the Internet of Things? 'Simples' – because cars are becoming IT systems, and IT systems are hackable. And why is that? Most of their suppliers have not carried out adequate 'due diligence'. In other words, the manufacturers have not made a comprehensive appraisal of how their products might cause harm and/or financial loss to end users or their property. In the worst-case scenario, this oversight or lack of vision could bankrupt the firms that make these devices, leaving them unable to fully compensate all users.

The high price of negligence

If that sounds ludicrously melodramatic, it's not. As I write this article, newspapers are claiming that it is entirely possible that Volkswagen will be forced to buy back cars fitted with emissions-rigging software. A lawyer in Seattle has filed a suit against VW seeking full restitution for owners of nearly 70,000 affected cars in the state of California, while a law professor at the University of Southern California states that under federal law, the 482,000 compromised cars cannot be driven legally anywhere in the US. As for forcing manufacturers to buy back the defective cars, a legal precedent was created in early 2015 when Fiat Chrysler agreed to make buy-back offers to owners of more than half a million pick-up trucks because they had defective steering parts that were not rectified, even after models were recalled. It's clear that manufacturers could be crippled financially if anything like this comes to pass. (Just imagine the cost of fitting devices to 1.2 million vehicles in the UK for intentionally subverting the emissions-testing regime.)

Those are just some of the real financial hazards facing automotive companies, and combining that with our recent review of the vulnerabilities of smart meters and the Internet of Things, and you have the main topic of this article – how and why your next car might be lethally unsafe to drive – and vitally, what the automobile industry is doing to avert disaster for you and its shareholders.

The threat defined

An organisation with a good understanding of the extent of the threat is British consultancy Automotive Knowledge Associates. Its managing director, Ian Dickie, explains succinctly: 'The modern vehicle is effectively a computer on wheels. It is heavily controlled by software and embedded devices and increasingly connected to the Internet in order to take benefit from a growing number of infotainment and safety applications. Just like any other computer connected to the web, the modern car is capable of being hacked.'

Control functions (brakes, steering, throttle control) that were traditionally governed mechanically, will increasingly be carried out by an ECU (engine control units) and EMS (engine management system) along wires or fibre optic cables. These are linked to a stack of sensors, actuators and, increasingly to the Internet (whether intentionally or not).

Who, why and how?

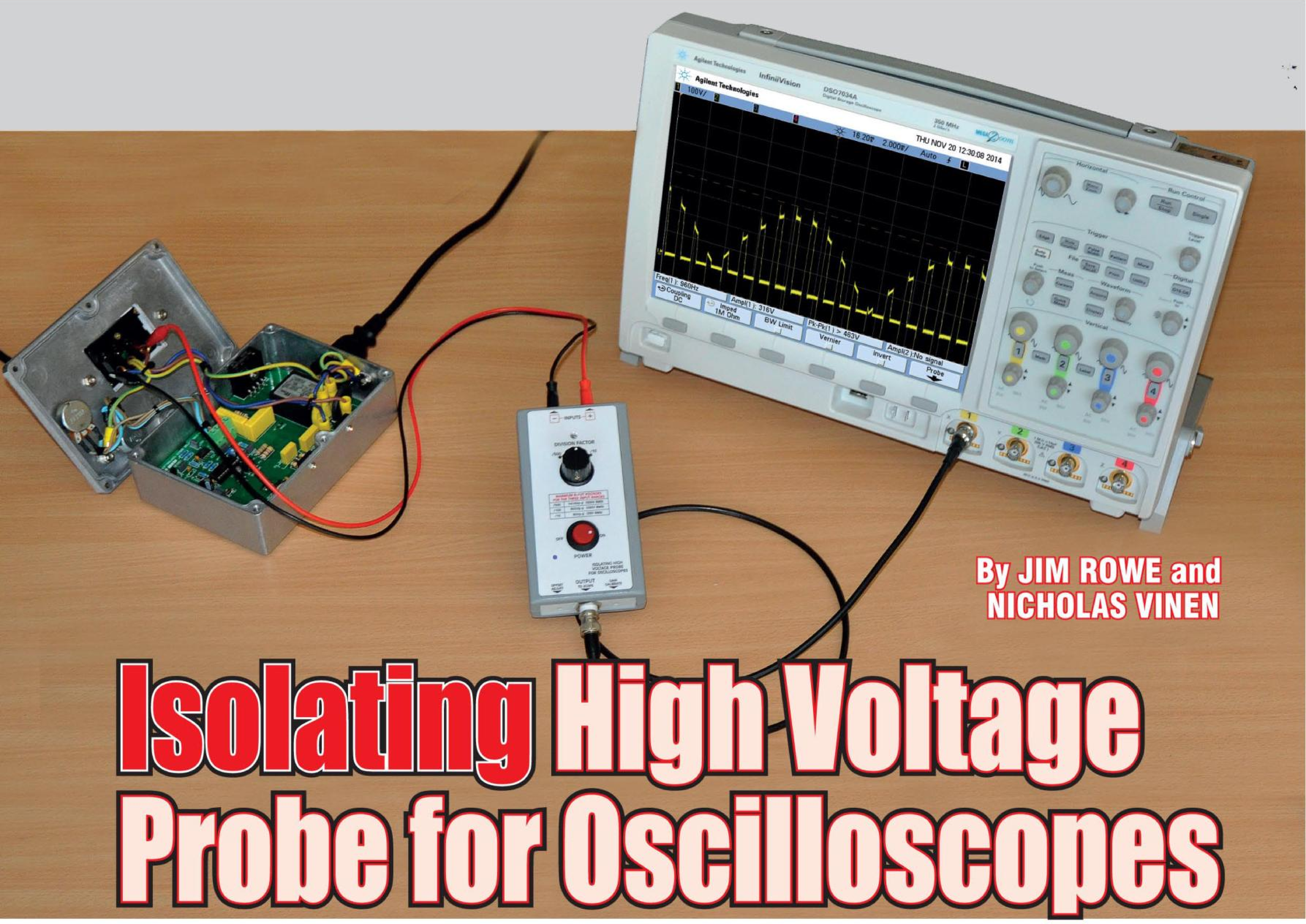
But who would wish to hack cars and why would they wish to? Terrorism is one extreme reason, explains Dickie. Benign and malicious demonstrations of vehicles driven off the road by well-intentioned whistle-blowers or criminals prove that it is possible for determined, well-resourced terrorists to make vehicles crash. Attacks of this kind, says Dickie, would be fiendishly difficult to carry out, but regardless of how many fatalities resulted, it is likely that thousands of people would be fearful of using their vehicles for a time and the resulting disruption and economic damage could be significant. He continues, 'There is also a concern that malware of any kind, even that created for 'sport' by hackers could enter the vehicle via the infotainment system (in-car Wi-Fi) and work their way into safety-critical systems, whether intended or not. While there are good reasons to worry about the vehicle safety implications of car hacking, history suggests that the connected car has more to fear from good old-fashioned theft and extortion. Picture the scene. You return to your vehicle on a cold, dark evening. Your electronic key will not open the doors or start the ignition. You receive an SMS from the criminal gang who have hacked the vehicle, demanding an electronic payment of EUR 100 to unlock the vehicle.'

Time for action

An article in industry magazine *EE Times* made the encouraging observation that current attack vectors (methods) have one thing in common: they do not scale, since they have to be custom-made for each and every case. For this reason, they will remain a matter for government agencies, secret services or similarly well-armed organisations. However, this may be only a temporary respite, since the elements of the connected car will soon become generic, as cars are integrated into cloud architectures and become a part of the Internet of Things. Having a wireless interface makes the vehicles inherently vulnerable to large-scale attacks. The danger increases as the 'business model' for the connected car calls for devices that access internal control units to read out data from the internal systems and eventually also write new content into them. As Ian Dickie points out, the automotive industry has a lot of ground to cover, but not much time to establish a secure basis for the era of the connected car.

Following an international conference on car security held last autumn in Dresden, Germany, *EE Times* reported a note of qualified optimism. 'The good news is that other industries have been to this point before,' stated Dominik Wee, partner at the McKinsey consultancy. Further good news, according to Wee, is that 83 per cent of manufacturers are aware of the threat. The less good news is that most of them haven't a clue yet what to do – only 41 per cent of the respondents have cybersecurity teams up and running. Wee's solution for the auto industry is to adopt the tiered security approach used in the IT industry – however, firewalls are only part of the solution and further research is clearly needed.

One thing is absolutely certain: any motor vehicle that defies the control of its driver could have perilous consequences, not only for those onboard, but also for the manufacturer.



By JIM ROWE and
NICHOLAS VINEN

Isolating High Voltage Probe for Oscilloscopes

Here's a low-cost project that will allow you to use your oscilloscope to observe and measure AC mains and other high voltage waveforms safely. It has three switchable input voltage ranges, wide bandwidth and high voltage isolation between input and output.

Observing and measuring waveforms on the AC mains and in other high voltage circuitry is quite dangerous using a standard oscilloscope or with the usual passive probes.

And by 'dangerous' we mean not only risking a possibly lethal electric shock to yourself, but also risking serious damage to your scope.

The danger arises mainly because the 'earthy' side of all scope inputs is connected to the scope's internal frame, which is normally itself earthed via the mains cable. And it needs to be earthed in this way, both for correct operation and for the safety of the operator – you. (An unearthed or 'floating' scope is an accident/disaster waiting to happen, so never be tempted!)

So the earthy side of all scope inputs is connected back to mains earth, which clearly poses a problem when you want to make measurements in circuits where everything is operating at a high or significant voltage with respect to earth.

After all, where do you attach the 'earth clip' of the scope probe?

For example, in a circuit connected directly to the 230VAC mains, you can't connect the earth clip to the live line because this will at least blow one or more fuses and may even start a fire which destroys either the scope or various components in the circuit you want to make measurements in.

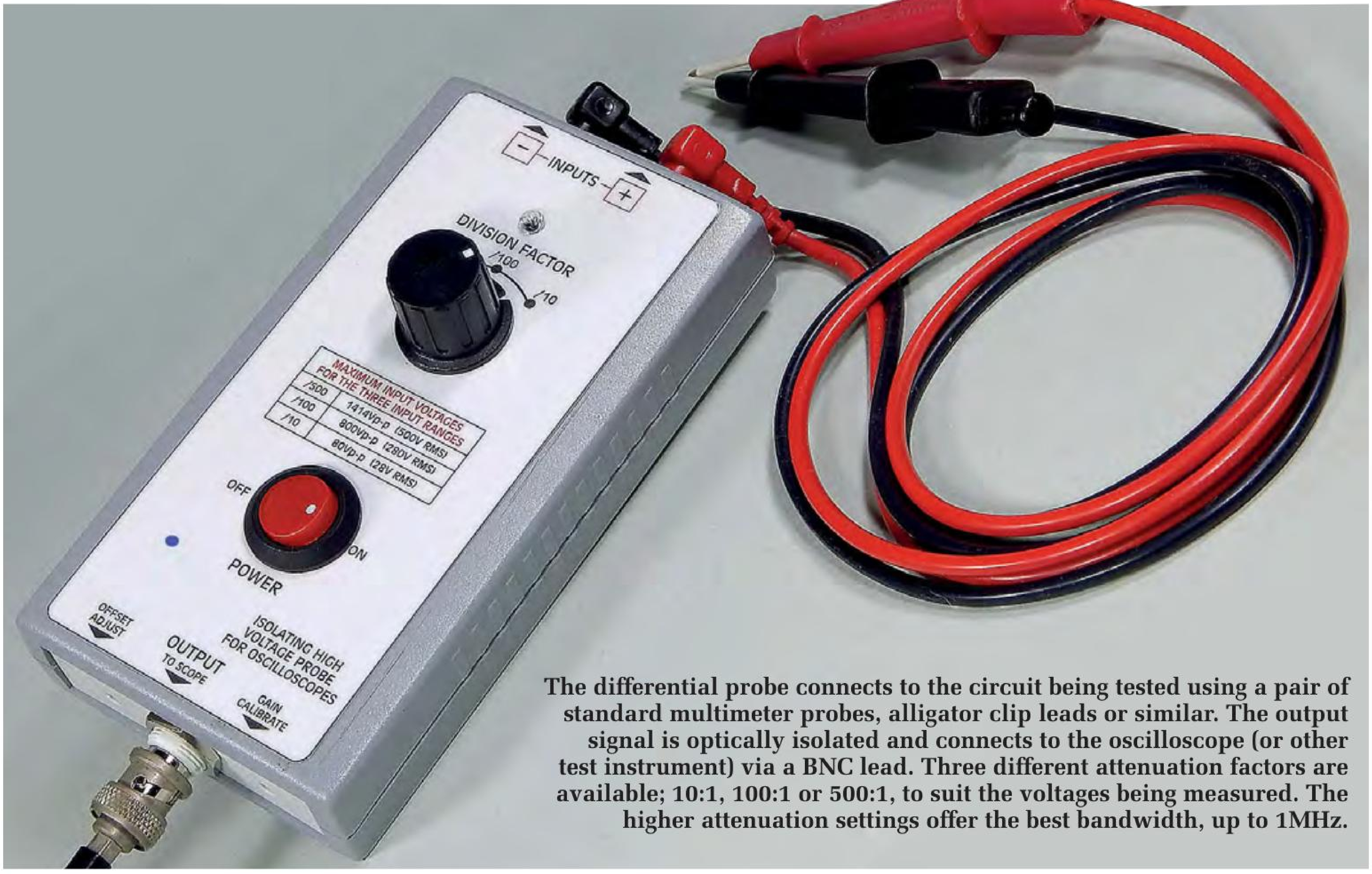
On the other hand you can't clip it to the neutral line either, because this is often itself floating at a significant voltage with respect to earth.

Another problem arises because the input attenuator on each channel of most scopes can only be switched to a maximum setting of 5V/division, which corresponds to 50V/division when a 10:1 divider probe is being used.

Because there are usually only 10 vertical divisions on the display, this means that only waveforms of up to 500Vp-p (peak-to-peak) can be displayed in their entirety.

Since the peak-to-peak amplitude of a 230V AC mains waveform is around 650V, this means that it simply can't be displayed or measured properly.

Things are even worse when it comes to making measurements in circuits



The differential probe connects to the circuit being tested using a pair of standard multimeter probes, alligator clip leads or similar. The output signal is optically isolated and connects to the oscilloscope (or other test instrument) via a BNC lead. Three different attenuation factors are available; 10:1, 100:1 or 500:1, to suit the voltages being measured. The higher attenuation settings offer the best bandwidth, up to 1MHz.

connected to the 3-phase 400VAC mains (415VAC with 240VAC mains).

It's true that 100:1 passive probes are available, and these can be used to extend a scope's upper voltage limit to a nominal 500V/division or 5kVp-p. But this type of probe does nothing to solve the main problem: where do you connect the probe's earth clip?

With most modern scopes having at least two input channels, there is usually only one way around this problem.

That's to use two 100:1 divider probes, one for each input channel, and remove the earth lead and clip from both probes.

Then the two channels are used in differential mode, to display and measure the voltage difference between the two tips. But unless the scope provides a differential (subtraction) mode (Ch1-Ch2 or Ch2-Ch1) display, it is not possible to achieve meaningful measurements.

Even if the scope offers a differential mode, the resulting waveform may not be a true portrayal because the scope's common-mode rejection may not be adequate when measuring high voltage circuits.

The best way of solving all of these problems is to use a special probe with full high-voltage isolation built in, like the one we're describing in this article.

By the way, we know that this type of probe is available commercially. But the cheapest we could find was about £200 and they rapidly move up into the four-digit price range.

Specifications

An isolating high voltage probe for oscilloscopes, providing three voltage-division ranges.

Division ranges	÷500 (optionally, ÷200), ÷100, ÷10
Input resistance	2.0MΩ|| ~10pF
Linearity	±0.05%
Bandwidth (see Fig.3)	10:1 range: DC to 500kHz (±0.5dB) 100:1 range: DC to 1MHz (±1dB) 500:1 range: DC to 900kHz (+0.2,–1dB)
Residual noise	typically 1.4mV RMS, 2.5mV peak-to-peak
Input-output isolation resistance	>10GΩ (500V)
Maximum working isolation voltage	1.4kV peak (1kV RMS)
Isolation test voltage	2.1kV peak (60 seconds)
Maximum transient I/O voltage	8kV peak (10 seconds)
Power supply	2 × 9V alkaline batteries
Typical operating current drain	6.0mA from battery 1, 1.0mA from battery 2

We estimate you should be able to build this new design for less than £50.

The new probe

Unlike other scope probes, this one is not meant to be held in the hand but sits on the bench – with its insulated input leads running to the circuit under test and its output connected to one input channel of the scope via a BNC-to-BNC cable.

It's housed in a small ABS instrument box measuring 150mm long, 80mm wide and 30mm high.

All of the probe's circuitry, including the two 9V alkaline batteries it uses for power, is housed inside the box. The input leads plug into insulated 'banana' sockets at one end of the box, while the BNC output connector emerges from the other end.

On the top of the box are the two main controls: a small rocker switch to turn the probe's

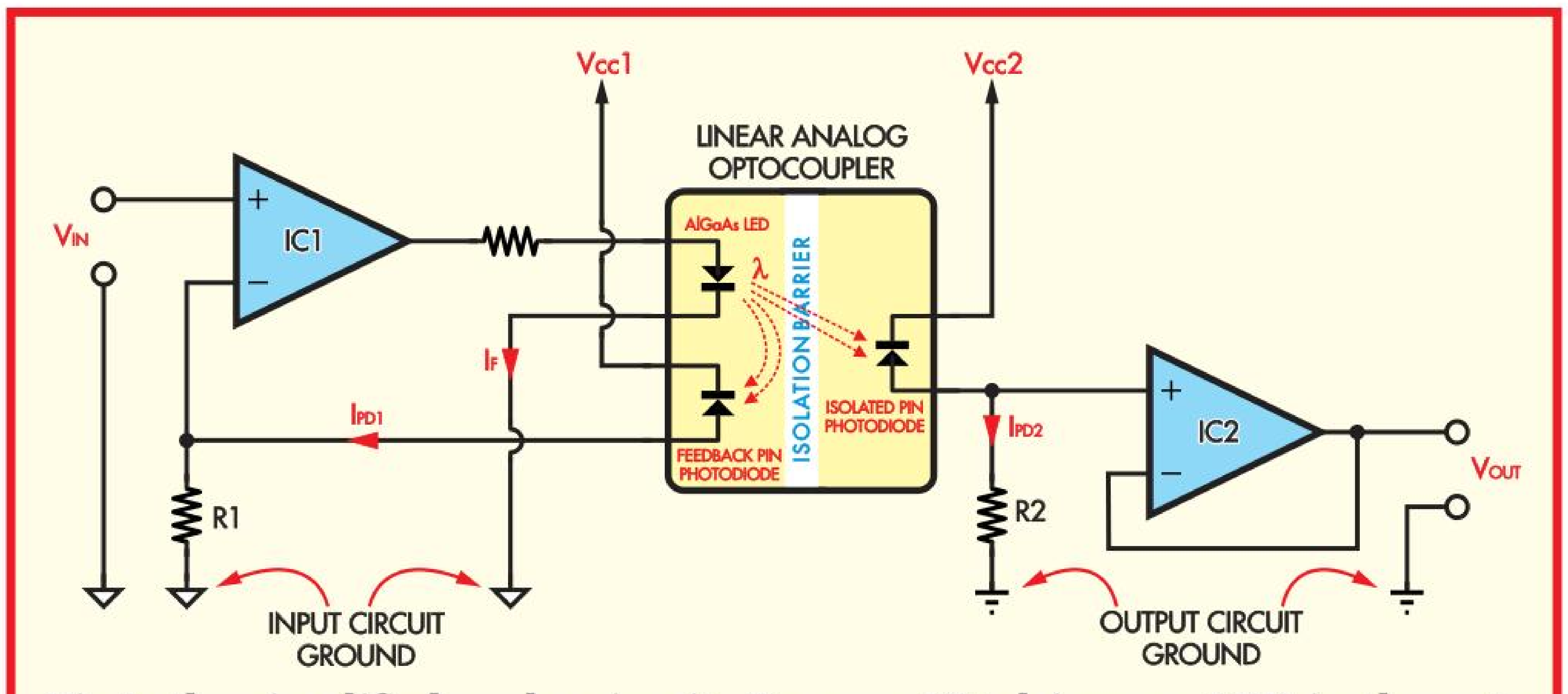

Vcc1
Vcc2
LINEAR ANALOG OPTOCOUPLER
AlGaAs LED
λ
ISOLATION BARRIER
ISOLATED PIN PHOTODIODE
FEEDBACK PIN PHOTODIODE
V_IN
IC1
IC2
I_F
I_PD1
I_PD2
R1
R2
V_OUT
INPUT CIRCUIT GROUND
OUTPUT CIRCUIT GROUND

Fig.1: the simplified probe circuit. Op amp IC1 drives an LED in the optocoupler with feedback from one of the photodiodes. IC2 generates the output signal from an identical, isolated photodiode. Note that $I_{PD1} \approx I_{PD2}$.

power on and off, and a rotary switch used to select one of three voltage division ranges: ÷500, ÷100 and ÷10.

The important point to grasp is that inside the box, there's a high-voltage 'galvanic isolation barrier' between the input and output circuitry.

This allows the input leads to be connected to circuits operating at many hundreds of volts above (or below) earth, despite the fact that the probe's output is directly connected to the earthed input of a scope – and without causing any distress or damage.

In fact, the isolation barrier inside the probe is able to withstand a peak 'working' voltage of 1414V, or 2100V for up to one minute (60 second), or as high as 8000V peak for transients of less than 10 seconds in duration.

And if you're curious about the isolation resistance between the inputs and the output, this is more than 10GΩ (10 gigaohms or 10,000MΩ).

How it works

The probe achieves this impressive performance because of a very special component: a high-linearity analogue optocoupler.

Understanding what this is and how it works is the key to understanding how the probe works as a whole, as we'll see shortly.

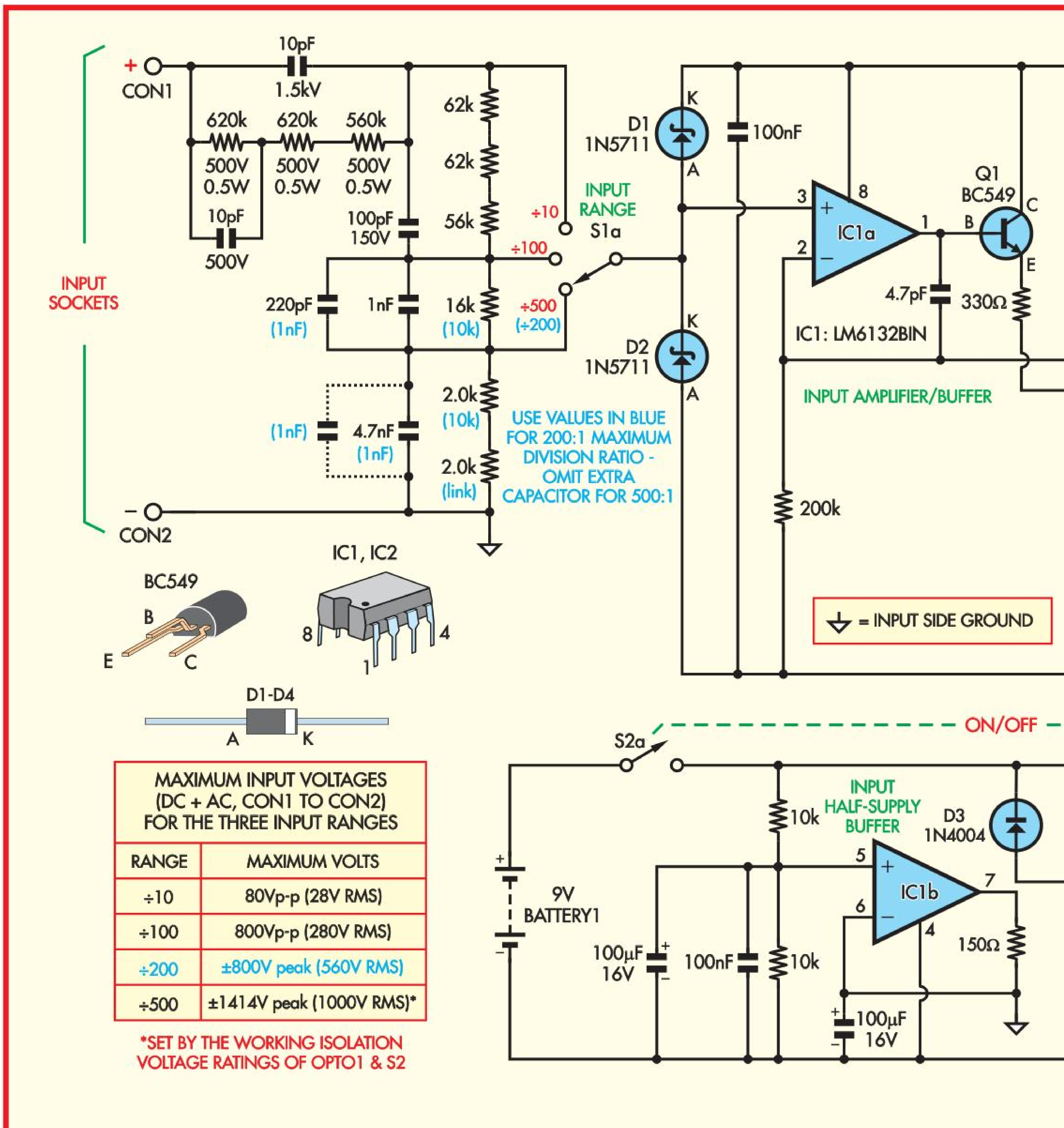
For now, refer to Fig.1, which shows a basic linear analogue isolation amplifier based on one of these devices.

The linear analogue optocoupler is like a conventional digital optocoupler, except that it has two PIN photodiodes sensing the infrared (IR) radiation emitted by the high performance AlGaAs LED. The two photodiodes are very closely matched in terms of their optical sensitivity and linearity.

The only difference between these 'identical twin' photodiodes is that while one of them is located on the far side of the device's internal voltaic isolation barrier (just like the output photodiode or transistor in a conventional optocoupler), the other is located back on the same side as the LED itself.

This allows the second photodiode to be used to provide linearising feedback, as a 'proxy' for the isolated output photodiode.

The close matching of the two photodiodes means that when the LED is passing a current I_F and emitting radiation to both photodiodes, the current I_{PD1} passed by the feedback photodiode will have a value very close to that of the current I_{PD2} passed by the isolated output photodiode. By passing current I_{PD1} through resistor R1 to produce a voltage proportional to the LED current I_F, we can use the resulting voltage to provide input amplifier IC1 with negative feedback. This linearises the operation of the input circuitry in converting input voltage V_{IN} into LED current I_F and


+
CON1
10pF
1.5kV
620k
620k
560k
500V 0.5W
500V 0.5W
500V 0.5W
10pF
500V
62k
62k
56k
100pF 150V
220pF (1nF)
1nF
16k (10k)
2.0k (10k)
2.0k (link)
(1nF)
4.7nF (1nF)
INPUT SOCKETS
–
CON2
÷10
÷100
÷500 (÷200)
INPUT RANGE S1a
USE VALUES IN BLUE FOR 200:1 MAXIMUM DIVISION RATIO - OMIT EXTRA CAPACITOR FOR 500:1
K
D1 1N5711
A
K
D2 1N5711
A
100nF
3
2
8
1
IC1a
4.7pF
Q1 BC549
B
C
E
330Ω
IC1: LM6132BIN
INPUT AMPLIFIER/BUFFER
200k
= INPUT SIDE GROUND
BC549
B
E
C
IC1, IC2
8
4
1
D1-D4
A
K
S2a
ON/OFF
9V BATTERY1
10k
100µF 16V
100nF
10k
INPUT HALF-SUPPLY BUFFER
5
6
7
4
IC1b
D3 1N4004
150Ω
100µF 16V

MAXIMUM INPUT VOLTAGES (DC + AC, CON1 TO CON2) FOR THE THREE INPUT RANGES

RANGE	MAXIMUM VOLTS
÷10	80Vp-p (28V RMS)
÷100	800Vp-p (280V RMS)
÷200	±800V peak (560V RMS)
÷500	±1414V peak (1000V RMS)*

*SET BY THE WORKING ISOLATION VOLTAGE RATINGS OF OPTO1 & S2

ISOLATING HIGH VOLTAGE PROBE FOR SCOPES

hence the IR radiation passing over the isolation barrier.

Since the output photodiode's current I_{PD2} is virtually the same as I_{PD1}, we are then able to use resistor R2 to convert this current back into a voltage V_{OUT} which is also directly proportional to V_{IN}.

(IC2 is then used to buffer V_{OUT}, to ensure that any load connected to the output does not upset this linearity.)

In fact, the resulting linear relationship between V_{OUT} and V_{IN} turns out to be very close to the ratio of R2 to R1, multiplied by the optocoupler's 'transfer gain' K3 (where $K3 = I_{PD2}/I_{PD1}$). So:

$$V_{OUT}/V_{IN} = K3.(R2/R1)$$

Because of the close matching between their twin photodiodes, most linear analogue optocouplers have a transfer gain K3 of very close to unity (1.0); within a few percent.

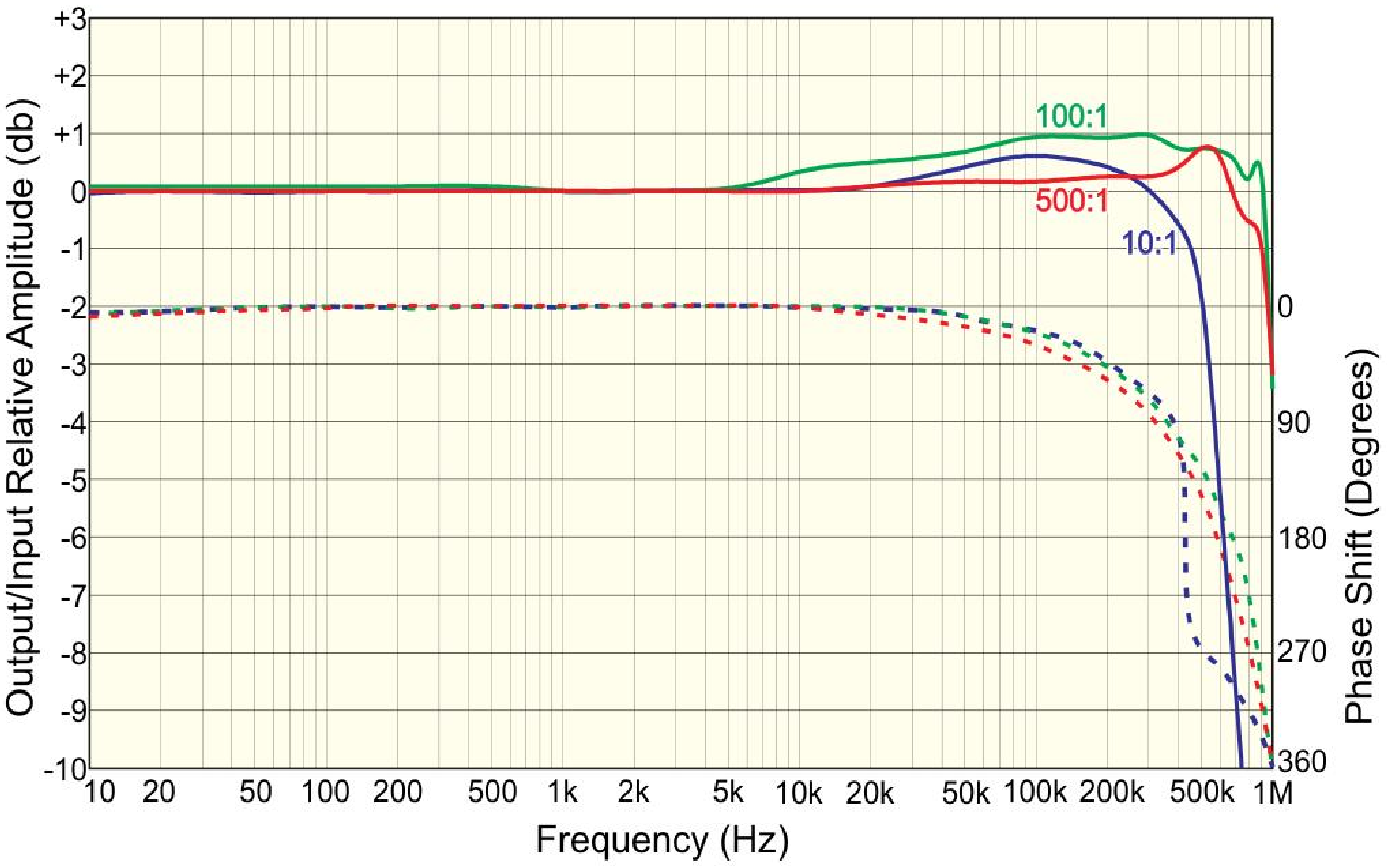


Fig.3: frequency response of the probe for each attenuation setting. The response is flattest at 500:1, but there is slightly more bandwidth at 100:1. The output/input signal phase shift for each setting is shown dashed, using the right y-axis.

Thus, the overall gain of the basic linear isolation amplifier of Fig.1 simplifies down to:

$$A = V_{OUT} / V_{IN} = (R2/R1)$$

It also turns out that we can compensate for any small deviation of the optocoupler's K3 away from unity, simply by 'tweaking' the value of R2.

So the overall gain of the isolation amplifier can be adjusted to be exactly unity, or whatever other figure we want it to be. Thus, we achieve linear analogue voltage gain while at the same time passing over a high voltage isolation barrier.

Performance

We tested our prototype by measuring signals under a number of different circumstances. The 'litmus test' was connecting the probe across the motor of a drill plugged into our *230V/10A Speed Controller For Universal Motors* (February-March 2015).

The result is shown in Scope1. This is gratifying, as it gives a clear picture of the voltage across the load, despite the fact that it's floating at mains potential and with the fast rise/fall times displayed correctly. In fact, this result is almost identical to what we get with a commercial differential probe.

With its ~1MHz bandwidth, our probe can be used to view signals with a higher switching frequency than this. For example, it could be used to view a floating MOSFET gate drive.

We did try it out connected across the output of an induction motor speed

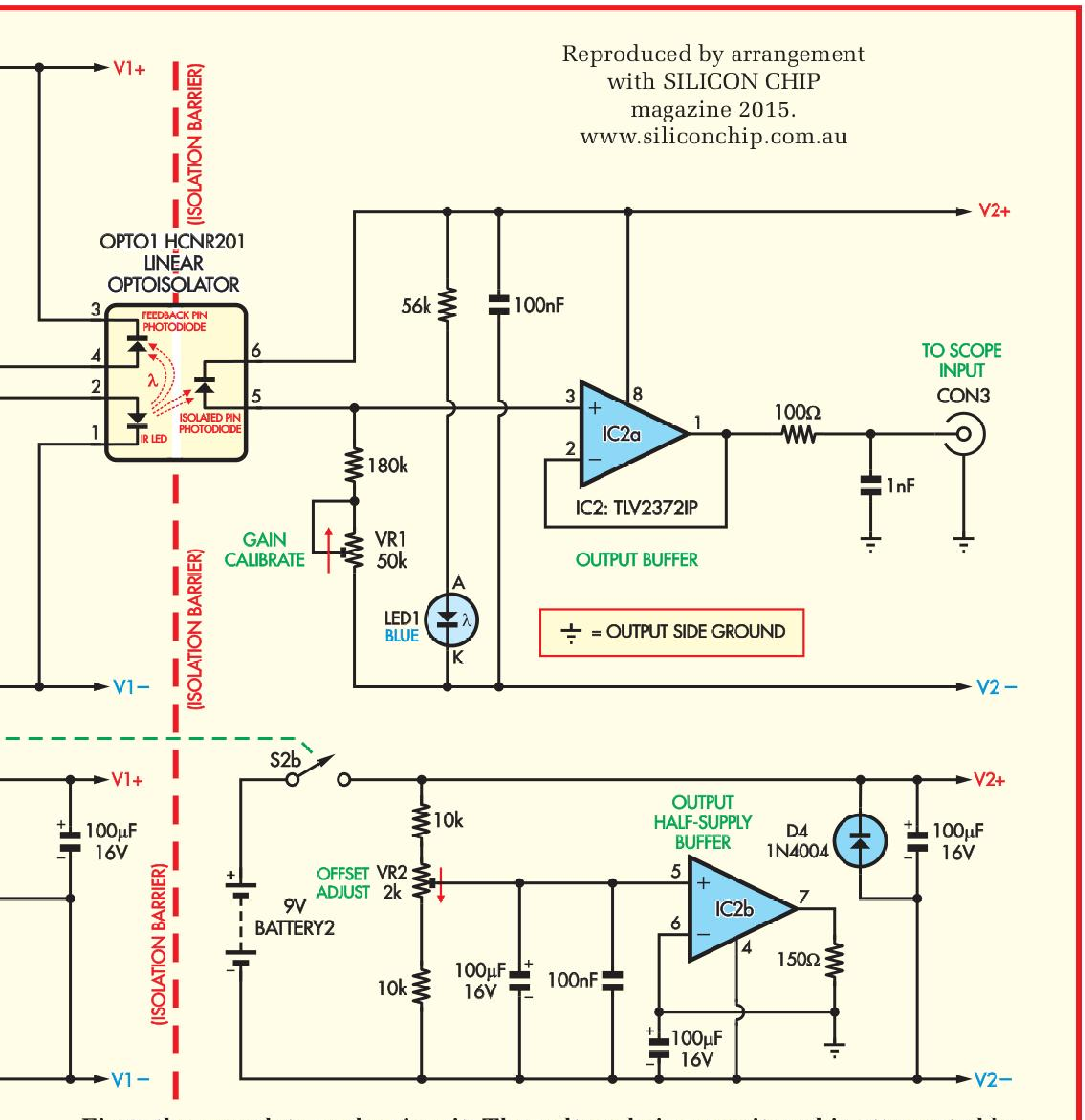

V1+
(ISOLATION BARRIER)
OPTO1 HCNR201
LINEAR
OPTOISOLATOR
FEEDBACK PIN PHOTODIODE
ISOLATED PIN PHOTODIODE
IR LED
λ
3
4
2
1
6
5
V2+
56k
100nF
180k
GAIN CALIBRATE
VR1 50k
LED1 BLUE
A
K
3
8
1
2
IC2a
IC2: TLV2372IP
OUTPUT BUFFER
100Ω
1nF
TO SCOPE INPUT
CON3
= OUTPUT SIDE GROUND
V1–
V2–
S2b
V1+
V2+
100µF 16V
10k
OFFSET ADJUST
VR2 2k
9V
BATTERY2
10k
100µF 16V
100nF
OUTPUT HALF-SUPPLY BUFFER
5
6
7
4
IC2b
D4 1N4004
100µF 16V
150Ω
100µF 16V
V1–
V2–

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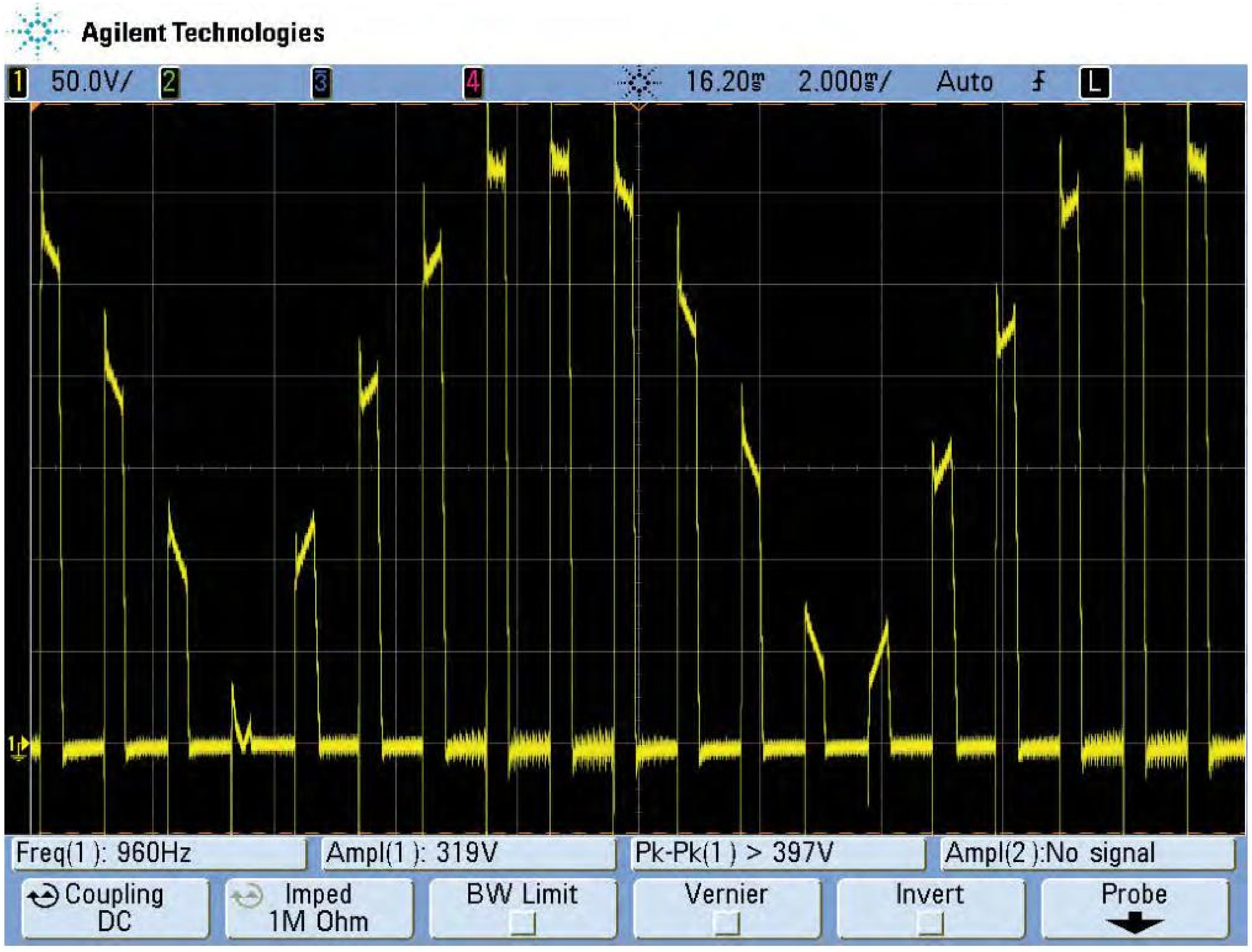
Fig.2: the complete probe circuit. The voltage being monitored is attenuated by a resistor/capacitor ladder and the selected tap connects to input pin 3 of IC1 via rotary switch S1. IC1b and IC2b provide half-supply rails to allow signals with bidirectional voltage swings to be probed.



Scope1: the voltage across a drill powered by our *230V/10A Speed Controller for Universal Motors*, showing a rectified mains waveform chopped at about 1kHz. The spikes are generated by the circuit; they are not measurement artefacts.

controller, which has a much higher switching frequency, 36kHz.

While we were able to get a reasonable picture of the output waveform (Scope3 shows it 'zoomed out'), the bandwidth of our probe is a little too low to show the very short pulses as a square wave. The voltage rise and fall times are simply too fast.

The full probe circuit

Now refer to the full circuit of Fig.2. The specific linear analogue optocoupler device we're using is the HCNR201, made by US firm Avago Technologies. This has very impressive features:

- **Low non-linearity: <0.01%**
- **Transfer gain: 1.00 ±5%**
- **Wide bandwidth: >1MHz**
- **Isolation: UL 5000V RMS for one minute**
- **Maximum working voltage: 1414V peak**
- **I/O test voltage: 2121V peak for 60s**
- **I/O transient over-voltage: 8000V for 10s**

The IR LED of optocoupler OPTO1 is driven by op amp IC1a via transistor Q1. The transistor is used as an emitter follower to provide the required current drive for the optocoupler's LED, since IC1 is a low-power device with low-current drive capability.

The output photodiode of OPTO1 is connected to the non-inverting input (pin 3) of output amplifier IC2a, in exactly the same way as shown in Fig.1. Trimpot VR1 with its series 180kΩ resistor takes the place of R2 in Fig.1, with VR1 allowing the exact value of R2 to be adjusted to set the overall gain of the probe to unity.

At the probe's front-end circuitry, the 200kΩ resistor connected between pin 2 of IC1a and the input circuit's negative rail is the equivalent of feedback resistor R1 in Fig.1.

You can see that the anode of OPTO1's feedback photodiode (pin 4) also connects to the 200kΩ resistor, as in Fig.1.

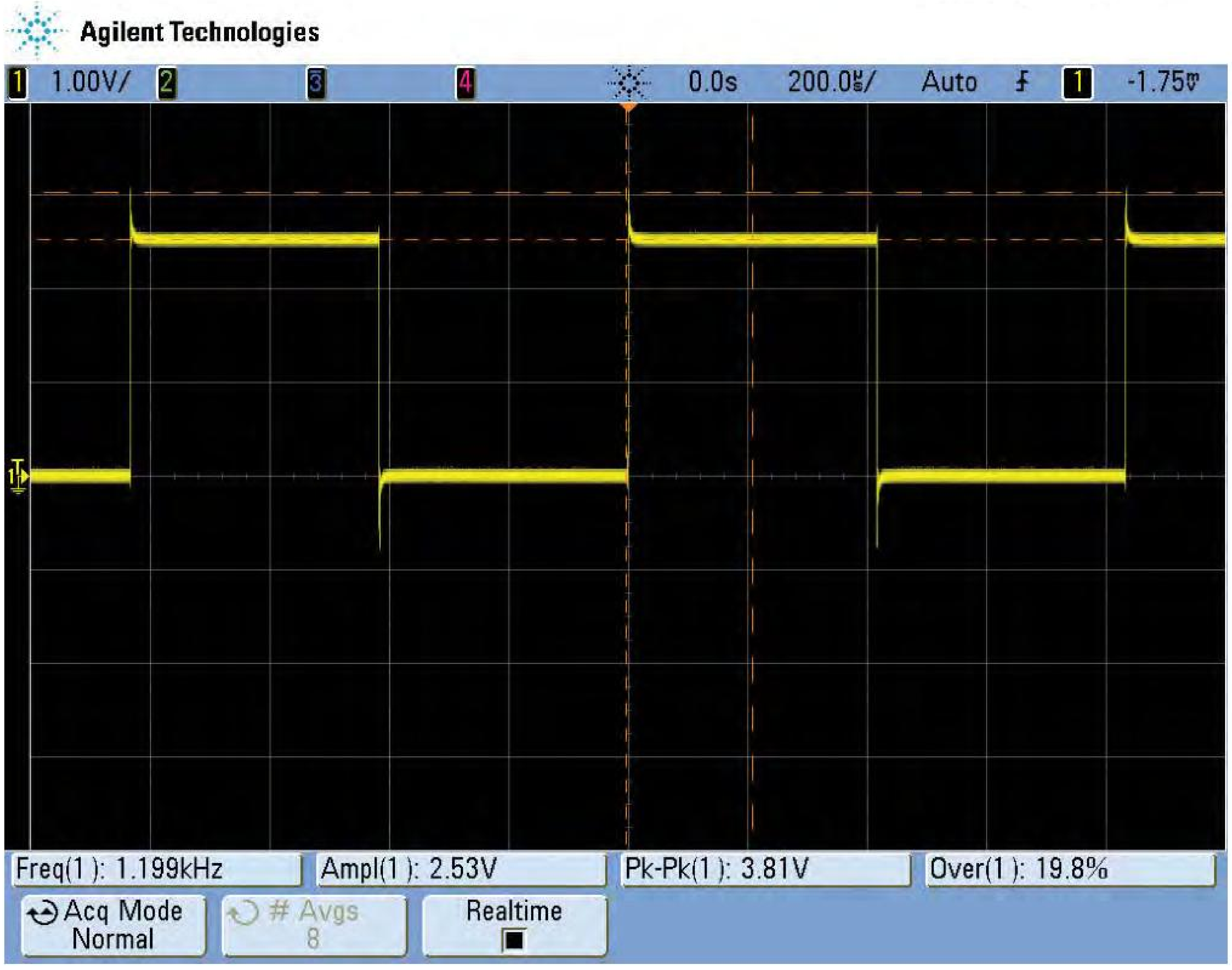
Note that the value of the 330Ω current-limiting resistor is important, since its ratio with the 200kΩ resistor sets the current gain of the opto-coupler and this affects the open-loop bandwidth of the surrounding circuit (ie, including IC1a). Increasing this resistor value reduces output overshoot, but also reduces overall bandwidth.

The 4.7pF capacitor also has an effect on bandwidth (in combination with the 330Ω resistor) and is required for the circuit to be stable, due to the phase shift inherent in the DC feedback path via the opto-coupler.

Input voltage divider

The non-inverting input of IC1a (pin 3) is connected to input connectors CON1 and CON2 via a switched voltage divider, to provide the probe's three division ranges.

The switching is done by S1a, one pole of a 4-pole, 3-position rotary switch (the other poles are unused). The input divider is arranged so that it provides a fixed input resistance of 2MΩ on all three ranges.



Scope2: a 1kHz scope compensation square wave as measured using the differential probe on its 10:1 setting. There are brief overshoot spikes at each edge, but otherwise the shape is square with no ringing or distortion.

Note the series of capacitors that has been connected in parallel with the divider resistors. These are required for a number of reasons.

First, they swamp the input capacitance of IC1a (exacerbated by the capacitance of D1 and D2), which would otherwise form a low-pass RC filter with the resistive divider network, seriously limiting the available bandwidth.

They also keep the AC impedance 'seen' by IC1a low, minimising noise and RF/hum pick-up.

An extra 10pF capacitor placed across the top 620kΩ resistor in the divider provides some extra compensation to cancel out the input capacitance of IC1a.

Regarding the voltage ratings of these components, 90% of the voltage applied across inputs CON1 and CON2 appears across the top three resistors and parallel capacitor. Given the 1414V peak rating of the device, the resistors must therefore be able to handle at least 500V and the 10pF capacitor, 1.5kV. Similarly, the 100pF capacitor sees 9% of the total voltage and thus must be rated for at least 150V.

Diodes D1 and D2 provide over-voltage protection for IC1a, ensuring that

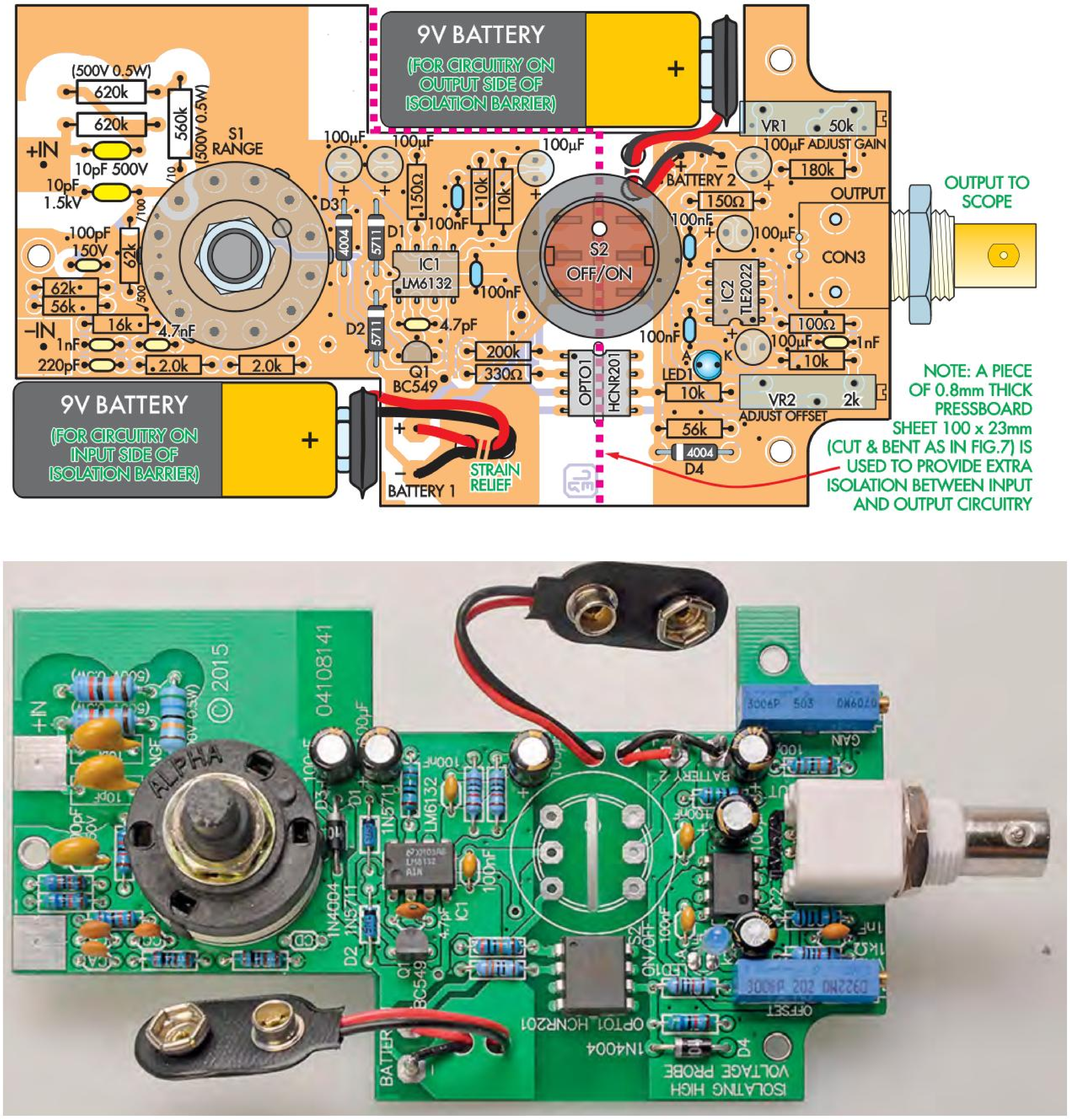
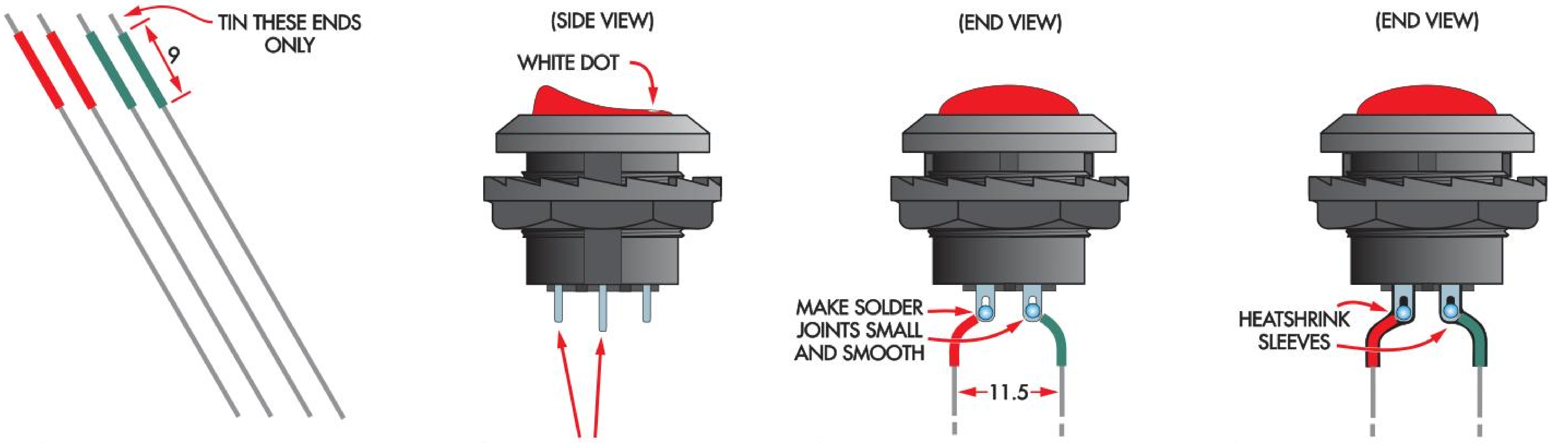

9V BATTERY
(FOR CIRCUITRY ON OUTPUT SIDE OF ISOLATION BARRIER)
(500V 0.5W)
620k
620k
560k
(500V 0.5W)
+IN
10pF 500V
10pF 1.5kV
100pF 150V
S1 RANGE
62k
62k
56k
16k
4.7nF
–IN
1nF
220pF
2.0k
2.0k
100μF
100μF
100μF
D3
4004
5711
D1
150Ω
100nF
10k
10k
IC1
LM6132
100nF
D2
5711
4.7pF
Q1
BC549
200k
330Ω
OPTO1
HCNR201
S2
OFF/ON
VR1
50k
100μF
ADJUST GAIN
BATTERY 2
180k
150Ω
OUTPUT
100nF
100μF
CON3
IC2
TLE2022
100nF
100Ω
100μF
1nF
10k
LED1
A
K
10k
VR2
2k
ADJUST OFFSET
56k
4004
D4
OUTPUT TO SCOPE
9V BATTERY
(FOR CIRCUITRY ON INPUT SIDE OF ISOLATION BARRIER)
BATTERY 1
STRAIN RELIEF
NOTE: A PIECE OF 0.8mm THICK PRESSBOARD SHEET 100 x 23mm (CUT & BENT AS IN FIG.7) IS USED TO PROVIDE EXTRA ISOLATION BETWEEN INPUT AND OUTPUT CIRCUITRY
© 2015
04108141
ALPHA
ISOLATING HIGH VOLTAGE PROBE

Fig.4 (top): the component overlay, which matches the near-same-size photo of the early prototype PCB (above). Note that the PCB is double-sided – make sure you solder the components to the correct side! S2 is not yet soldered in place in the photo, but is shown *in situ* above.


TIN THESE ENDS ONLY
9
(SIDE VIEW)
WHITE DOT
(END VIEW)
MAKE SOLDER JOINTS SMALL AND SMOOTH
11.5
(END VIEW)
HEATSHRINK SLEEVES

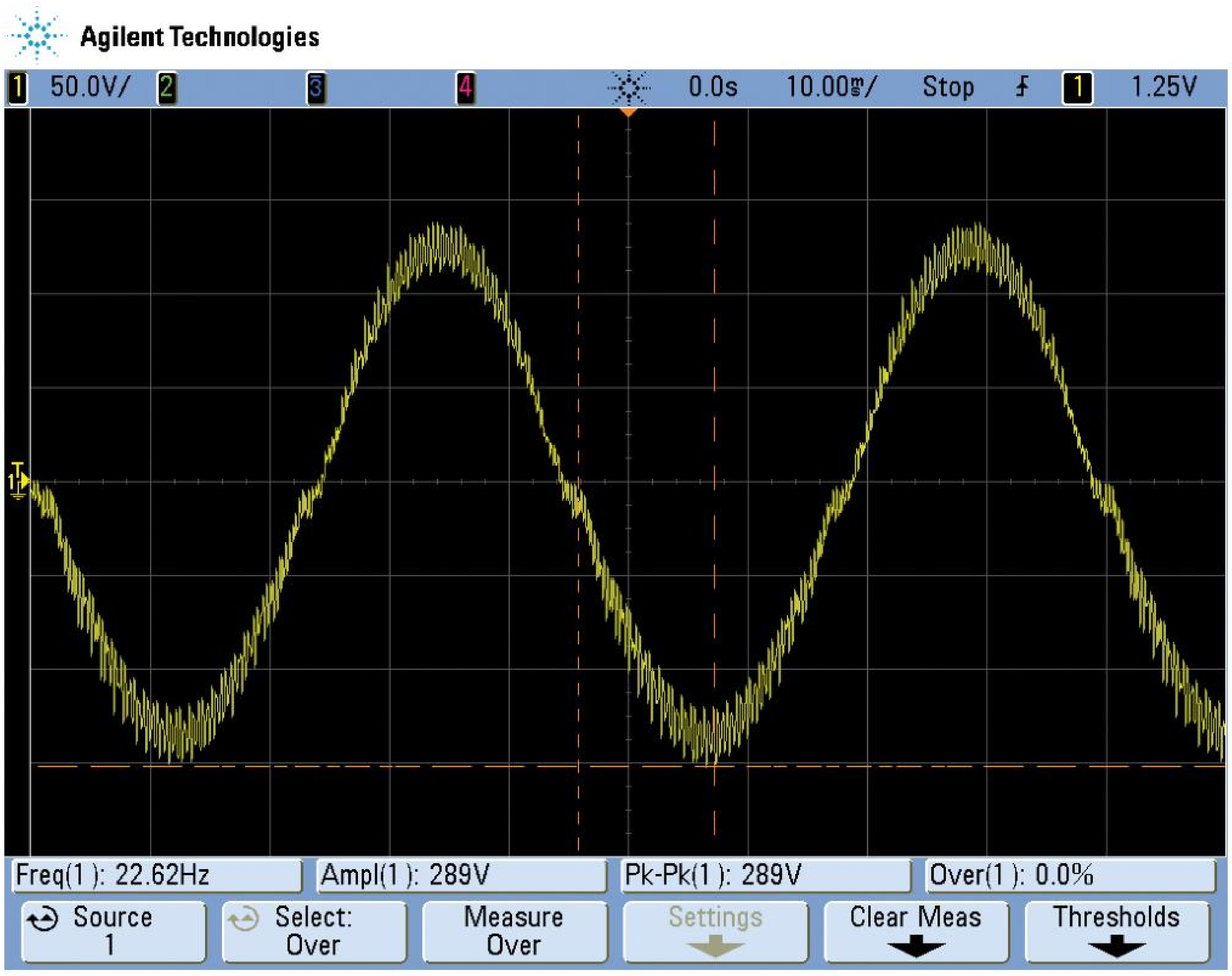
① CUT 4 x 50mm LONG PIECES OF HOOKUP WIRE, STRIPPING INSULATION 4mm FROM ONE END & 37mm FROM THE OTHER END & LEAVING 9mm OF INSULATION ON EACH WIRE. TIN THE SHORT BARED ENDS OF ALL FOUR WIRES

② IDENTIFY THE SWITCH LUGS TO WHICH THE WIRES WILL BE SOLDERED, ON BOTH SIDES OF THE SWITCH

③ SOLDER THE SHORT END OF EACH WIRE TO A SWITCH LUG, MAKING EACH JOINT SMALL & SMOOTH. THEN SPLAY EACH PAIR OF LEADS OUTWARDS TO SPACE THEM 11.5mm APART

④ CUT 4 x 11mm LONG PIECES OF 3mm DIAMETER HEATSHRINK TUBING AND SLIP OVER EACH WIRE & SWITCH LUG. THEN SHRINK THEM IN TIGHTLY USING A HOT AIR GUN OR THE SHANK OF A SOLDERING IRON.

Fig.5: follow these steps in soldering leads to, then securing, S2 to the PCB.



Scope3: the voltage across two outputs of an induction motor speed controller with an incandescent lamp as a load. The scope performs a sort of averaging when zoomed out like this, revealing the PWM-modulated sinewave shape.

input pin 3 cannot swing higher than 0.4V above the input circuit's positive supply rail (V1+) or lower than 0.4V below its negative rail (V1–). This prevents IC1 from damage should you accidentally connect the probe inputs to high voltages when switch S1 is switched to the low voltage (÷10) range.

The 100Ω resistor at IC2a's output isolates this buffer from any cable capacitance or input capacitance of the scope.

We've also added a 1nF capacitor to form an RC low-pass filter here, to compensate for a peak in the frequency response of the circuit surrounding the opto-coupler just below 1MHz (ie, its roll-off point). This gives a flatter frequency response (Fig.3).

Note that we've also shown some alternative divider component values in the circuit. If used, these change the ÷500 range to ÷200. This results in a better signal-to-noise ratio but with a more limited input voltage range before saturation (see table in Fig.2).

Note also that the resulting 800V peak rating is sufficient for working with even 3-phase mains.

Power supply

It is important that the input and output circuits of the probe are operated from separate power supplies, since they are on opposite sides of the isolation barrier.

So, each section operates from its own 9V alkaline battery, with the input section running from battery 1 and the output section from battery 2.

We are using op amps 1C1b and IC2b as buffers to give each supply its own half-supply 'reference ground'. The buffers are very similar, in each case using a resistive divider to establish a battery 'centre tap', with the ICs connected as voltage followers to provide the necessary current capability. (The 150Ω resistors and 100µF capacitors are to ensure that the voltage followers remain stable.)

In the case of the input circuitry, the purpose of IC1b is to establish a 'reference ground' voltage level for the negative input connector CON2, so that when there is no input to the probe the non-inverting input of IC1a is biased midway between the V1+ and V1– rails. This allows the input circuit to operate the IR LED inside OPTO1 at close to 'half brightness', while also allowing IC1a to cope with the maximum possible AC voltage swing.

On the output side, IC2b is again there to provide a half-supply reference ground, for the output connector CON3. And by making the exact reference voltage variable using trimpot VR2, we allow cancelling of any output offset voltage that might be caused by differences between the photodiodes inside OPTO1 at the quiescent current level.

Although the two supplies are on opposite sides of the probe's isolation barrier, we switch them on and off in tandem using S2a and S2b, the two poles of a 250V AC-rated rocker switch.

Typical mains-rated switches of this type are rated to withstand 1000V RMS, which just happens to be exactly what OPTO1 is able to withstand.

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Parts List – Isolating High Voltage Probe for Oscilloscopes

1 PCB, available from the *EPE PCB Service*, coded 04108141, 70 × 122mm
1 ABS instrument box, 150 × 80 × 30mm
1 4-pole 3-position rotary switch, (S1)
1 knob to suit S1, <25mm diameter
1 DPDT, 250V AC-rated rocker switch, single hole mounting (S2)
2 banana sockets, fully insulated, 1 red, 1 black (CON1, CON2)
1 PCB-BNC socket (CON3)
1 6mm-long untapped spacer
1 15mm-long M3 tapped nylon spacer
1 15mm-long M3 nylon machine screw (cut from a 25mm-long screw)
1 6mm-long M3 machine screw
2 16.5mm-long untapped spacers (cut from 25mm-long spacers)
2 25mm-long 6G or 7G countersunk self tapping screws
4 3.5mm ID flat washers
2 9V alkaline batteries
2 battery snap leads to suit
4 PCB terminal pins
1 100 × 26mm piece of 0.8mm Pressboard or Presspahn/Elephantide sheet

Semiconductors
1 LM6132AIN/BIN dual high-speed op amp (IC1) [element14 order code 9493980]
1 TLE2022CPE4 dual low-current op amp (IC2) [element14 order code 1234686]
1 HCNR201-050E high-speed linear optocoupler (OPTO1) [Digi-Key 516-2379-5-ND]
1 BC549 NPN transistor (Q1)
1 3mm blue LED (LED1)
2 1N5711 Schottky diodes (D1,D2)
2 1N4004 1A diodes (D3,D4)

Capacitors
6 100µF 10V/16V PC electrolytic
4 100nF multilayer monolithic ceramic
1 4.7nF 50V disc ceramic
2 1nF 50V disc ceramic
1 220pF 50V disc ceramic
1 100pF 150V* disc ceramic
2 10pF 1.5kV* disc ceramic
1 4.7pF C0G/NP0 disc ceramic

* 7.62mm lead spacing; 3kV types suitable

Changes for 200:1 option:

- **Delete 220pF and 4.7nF ceramic capacitor**
- **Add three more 1nF ceramic capacitors**
- **Delete 16kΩ and two 2kΩ resistors**
- **Add two more 10kΩ resistors**

Resistors (1% metal film 1/4W unless specified)
2 620kΩ 500V 1% 1/2W
1 560kΩ 500V 1% 1/2W (eg, Vishay HVR37)
1 200kΩ 1 180kΩ 2 62kΩ 2 56kΩ 1 16kΩ
4 10kΩ 2 2.0kΩ 1 330Ω 2 150Ω 1 100Ω
1 50kΩ multi-turn horizontal adjustable trimpot (VR1)
1 2kΩ multi-turn horizontal adjustable trimpot (VR2)

To be safe, we've added some extra insulation between the leads connecting to the switch (as we'll explain soon).

Diodes D3 and D4 are connected to the switch such that they are reverse-biased normally and thus do not affect circuit performance at all. But if a battery happens to be connected backwards while S2 is on (easy enough to do, at least briefly), the diode will limit the voltage applied to IC1 or IC2 to no more than –1V, protecting it from damage.

LED1 is fitted to make it harder to forget to turn the unit off when you've finished using it. As it's a high-brightness blue LED, it only requires 100µA to operate, so it doesn't add much to the battery drain during operation.

Building the probe

As mentioned earlier, all of the components and circuitry of the probe are built into a small ABS instrument case measuring 150 × 80 × 30mm.

In fact, everything except the two 9V batteries, on/off switch S2 and input jacks CON1 and CON2 is mounted on a single PCB measuring 122 × 70mm and coded 04108141. The board has cutouts on each side to provide spaces for the two 9V batteries, as you can see from the overlay diagram of Fig.4.

On/off switch S2 mounts on the top of the case on the centre line and about 1/3 of the distance up from the output end, with short insulated and splayed leads connecting its lugs to the matching pads on the PCB.

The two insulated input jacks – CON1 and CON2 – mount in the input end panel of the case with their connection lugs wired to the matching pads on that end of the PCB.

Output BNC connector CON3 is mounted directly onto the PCB at the centre of the output end, with trimpots VR1 and VR2 spaced equally on either side. The trimpots are then easily adjusted using a small screwdriver or alignment tool, through matching holes in that end of the case.

To wire up the probe PCB, fit the components in the usual order: first the resistors (including VR1 and VR2), followed by the four diodes, the smaller capacitors and the six 100µF electrolytics – taking care to fit the diodes and electrolytics with the correct polarity. Take care not to get the two types of diode mixed up.

Next, mount transistor Q1, followed by the range switch S1, after cutting its spindle at a distance of 12mm from the end of the threaded ferrule. Then fit the switch to the PCB, taking care to use the orientation shown in Fig.4. Next, fit IC1 and IC2, again making sure you orient each one as shown.

The next component to be added to the PCB is the HCNR201 linear analogue optocoupler (OPTO1).

Although it comes in an 8-pin DIL package, it has wider pin spacing than usual: 0.4-inch (10.16mm) rather than 0.3-inch or 7.62mm. It's fitted to the PCB with the 'notch' end towards the top.

After this, fit BNC output connector CON3 at the right centre of the PCB, midway between trimpots VR1 and VR2, followed by the four PCB terminal pins used to make the connections between the two battery snap leads and the PCB.

Two of these pins are soldered into the pads just below the cutout for battery 1 at upper left, while the other two go just to the left of the cutout at lower right, for battery 2. You can see these quite clearly in Fig.4.

Mount LED1 with the bottom of its lens 20mm from the top of the PCB. This will be with virtually the full lead length.

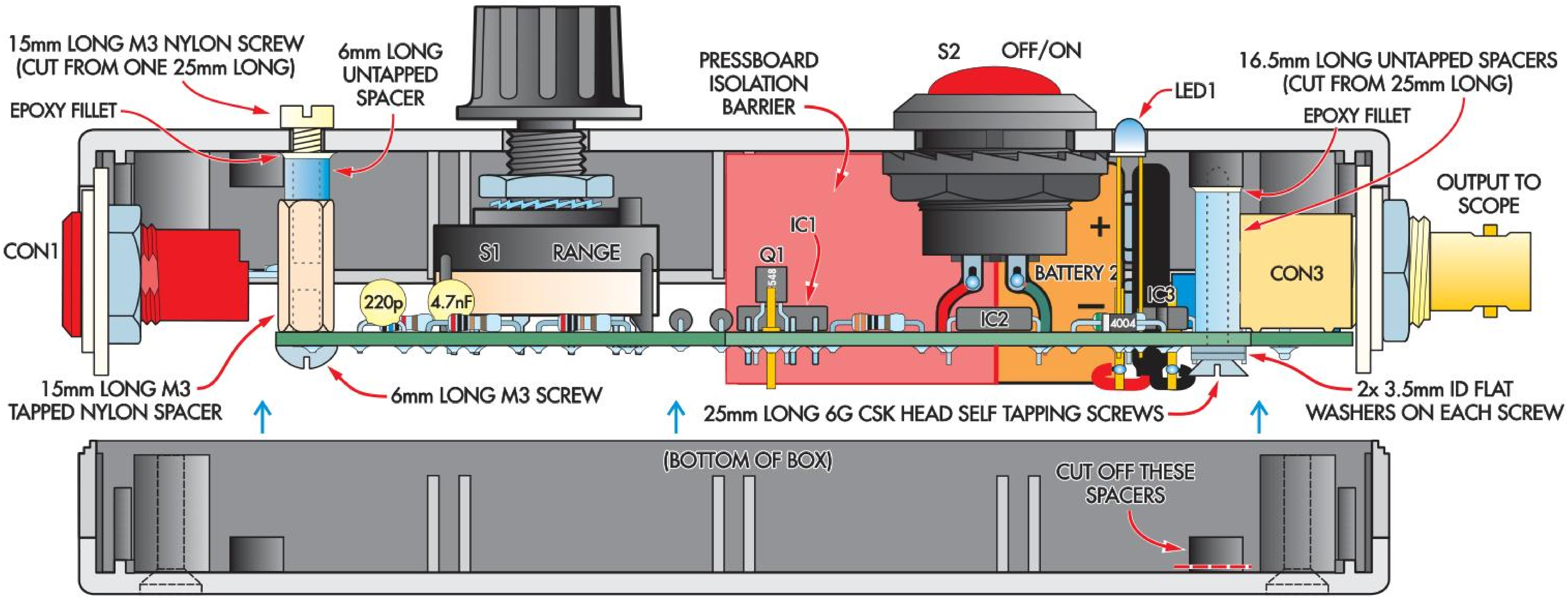

15mm LONG M3 NYLON SCREW (CUT FROM ONE 25mm LONG)
EPOXY FILLET
6mm LONG UNTAPPED SPACER
PRESSBOARD ISOLATION BARRIER
S2 OFF/ON
LED1
16.5mm LONG UNTAPPED SPACERS (CUT FROM 25mm LONG)
EPOXY FILLET
OUTPUT TO SCOPE
CON1
S1
RANGE
IC1
Q1
548
220p
4.7nF
+
BATTERY 2
–
IC2
IC3
4004
CON3
15mm LONG M3 TAPPED NYLON SPACER
6mm LONG M3 SCREW
25mm LONG 6G CSK HEAD SELF TAPPING SCREWS
2x 3.5mm ID FLAT WASHERS ON EACH SCREW
(BOTTOM OF BOX)
CUT OFF THESE SPACERS

Fig.6: how it all fits into the case, as if looking through the side. Opposite is a photo of the completed unit.

Finally, cut the two battery snap leads themselves to about 45-50mm long (measured from the snap) and strip back about 5mm of the insulation from the wire ends.

Thread the wires through the stress relief holes provided on the PCB and solder them to the terminal pins, again as shown in Fig.4.

Your probe PCB assembly should now be complete, and can be placed aside while you prepare the box.

Preparing the box

There are no holes to be drilled in the bottom half of the case. All the holes are drilled/reamed in the top half and in the two removable end panels. But, as there are only nine holes in all, this shouldn't be a problem. The size and location of all of the holes are shown in a drilling guide PDF, which can be downloaded from: **epemag.com**

After drilling the smaller holes and reaming the larger holes to size, use a jeweller's file or a sharp hobby knife to remove any burrs left around each hole on both the inside and the outside.

To make a 'dress' front panel for the probe you can make a photocopy of our artwork in Fig.8 (or download it from: **epemag.com**) and then laminate it in a plastic sleeve for protection. After this, it can be trimmed to size and attached to the top of the case using double-sided adhesive tape. Then cut holes in the dress panel for fitting the top PCB mounting screw, S2 and the control spindle for S1, using a sharp hobby knife and guided by the holes you have already cut and reamed in the case underneath.

Making the isolation barrier

Before you begin fitting everything into the case, you need to prepare the isolation barrier which will provide additional isolation between the input and output circuitry and their batteries.

The barrier is cut from a 100 × 26mm rectangle of 0.8mm-thick pressboard sheet (similar to Presspahn Elephantide), using the upper diagram of Fig.7 as a guide, and then bent up as shown in the lower diagram.

Preparing S2

The next step is to prepare on/off switch S2 by fitting it with the four well-insulated wires which will connect it to the PCB. As you can see from Fig 5.1 this needs four 50mm lengths of insulated wire, each with the insulation stripped by 4mm from one end but 37mm from the other end. (The long bared ends are to make assembly easier later.)

We are using the two centre lugs and those at the ends opposite to the white dot on the red rocker actuator at the top of S2, as shown on the left in Fig 5.2.

After soldering the short ends of the four wires to these switch lugs, each pair of wires is splayed away from the other pair as shown Fig 5.3, so that the pairs are spaced about 11.5mm apart.

Then cut four 11mm-long lengths of 3mm diameter heatshrink tubing, and push each of these sleeves up one of the wires as far as it will go – that is, over the switch lug and the solder joint and until its top end is hard against the rear of the switch body (see Fig 5.4).

After this, use a hot air gun or the hot shank of your soldering iron to shrink each of the sleeves firmly into position around the wires and switch lugs. Then your 'S2 switch assembly' should be complete, and ready to be fitted into place in the 18mm hole on the top of the case.

This is done by unscrewing the large plastic nut, and then passing the switch and its splayed wires down into the box via the 18mm hole. Then screw the nut back on again inside the box, to hold it in position.

But before you tighten the nut completely, make sure that the switch is positioned so that the white dot on its rocker actuator is positioned on the right, directly in line with the 'ON' label of the dress front panel.

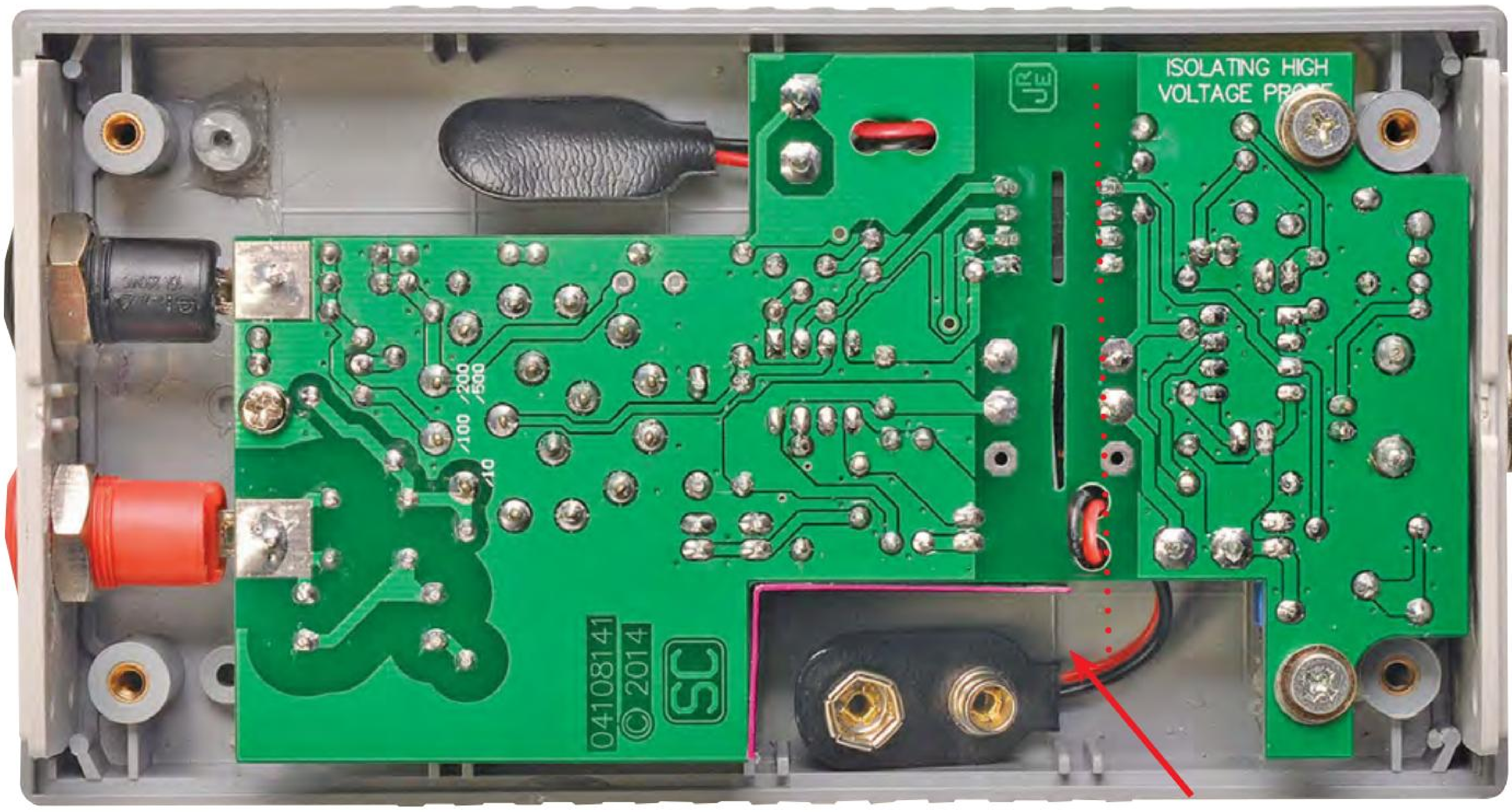
Next, cut the two 25mm untapped spacers down to a length of 16.5mm, using a jeweller's saw and smooth off the cut ends using a small file.

Then fasten them temporarily to the two mounting spacers moulded into the inside of the top of the case (at the output end), using the two 25mm-long countersink-head self-tapping screws with about five or six small flat washers under each screw head as packing, so the screws don't enter the moulded spacers very far – just enough to hold the 16.5mm spacers in place.

Then pass a 15mm-long nylon M3 screw (cut from a 25mm-long screw) down through the central hole near the input end of the case front panel, slip the 6mm untapped spacer up over the end of the screw and fit an M3 nut – screwing it up to hold the 6mm spacer firmly against the underside of the front panel.

You should now be almost ready to apply a fillet of epoxy cement around the top end of each of the three spacers, to hold them in place securely.

But there's one more thing to do first: fit the Pressboard isolation barrier into the top half of the case. Its 26mm-high 'L section' should be over on the side ready to slip into the cutout for battery 2, with the 20mm-



Take note of the order of assembly in the text, especially the Presspahn isolation barrier (arrowed) which wraps around the lower battery and sits across the middle of the PCB, as indicated by the red dotted line. This is all necessary to ensure good isolation between the battery and PCB and between the two poles of the power switch.

high section with its cutouts for S2 and OPTO1 passing 'east-west' and aligned centrally between the contacts at the rear of S2.

Once you're happy that it's in the correct position, it can be secured there using a few small dabs of epoxy adhesive between the barrier and the inside of the case top.

Then, while you have the epoxy cement mixed up, cement the spacers to the case top as well.

When the cement has had time to cure, you can unscrew both of the 25mm long self-tappers and remove all but two of the washers on each, ready to secure the PCB shortly.

At the same time you can unscrew the 15mm M3 screw and its nut holding the 6mm spacer in place, and you'll be ready for final assembly.

Final assembly

The next step is to attach the 15mm-long M3 tapped spacer to the PCB (at top centre), using a 6mm-long M3 screw passing up from underneath. It's a good idea to tighten this screw firmly (but not *too* firmly) using a screwdriver, with the spacer held by a small spanner or nut driver.

After this, mount the two input connectors CON1 and CON2 into the input end panel of the case, with the red one on the right as viewed from behind the panel. Tighten their nuts to secure them in place, and then solder a short length of tinned copper wire to the rear lug of each connector.

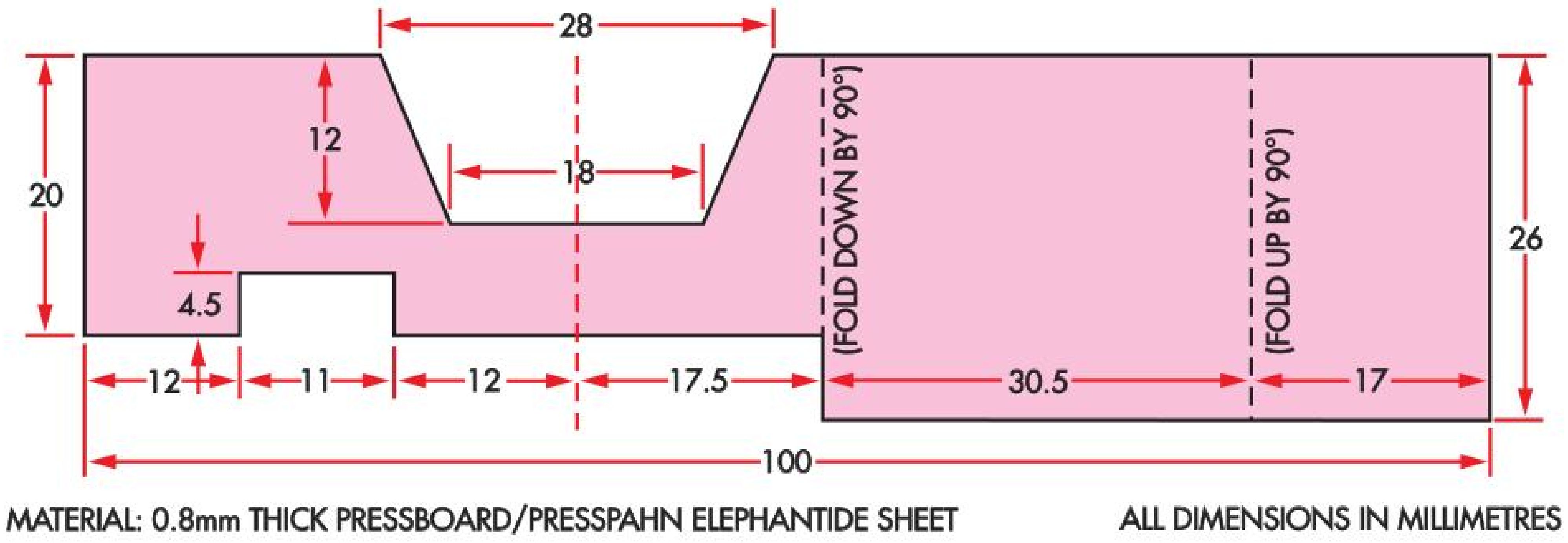
Then, with the centre axis of the two connectors positioned about 6mm above the top end of the PCB, solder each wire to its matching pad on the PCB. These pads are provided with a centre hole, so you can pass each wire down through the hole before soldering.

Next, fit the output end panel of the case over the shank of CON3, after removing its nut. Then screw the nut back on again, to complete the PCB-and-end panels assembly.

By now you should be ready to fit this completed board assembly up into the top half of the case, by introducing it so that each of the two end panels slips into the matching slots in the ends of the case half. The four wires from S2 pass down through their matching holes in the PCB and the shaft and threaded ferrule of rotary switch S1 pass up through their matching hole in the top of the case.

When the assembly can't be pushed in any further, you should be able to secure it all together by screwing the two self-tapping screws back into the matching holes of the mounting spacers moulded into that end of the case top, and also by passing the 15mm-long nylon screw down through the matching hole in the centre of the input end of the case top, so it passes down through the 6mm untapped spacer and can then be screwed into the top of the 15mm-long M3 tapped spacer.

If you found this description somewhat confusing, examine Fig.6. This shows what you'll be working towards.


28
12
18
20
4.5
(FOLD DOWN BY 90°)
(FOLD UP BY 90°)
26
12
11
12
17.5
30.5
17
100
MATERIAL: 0.8mm THICK PRESSBOARD/PRESSPAHN ELEPHANTIDE SHEET
ALL DIMENSIONS IN MILLIMETRES

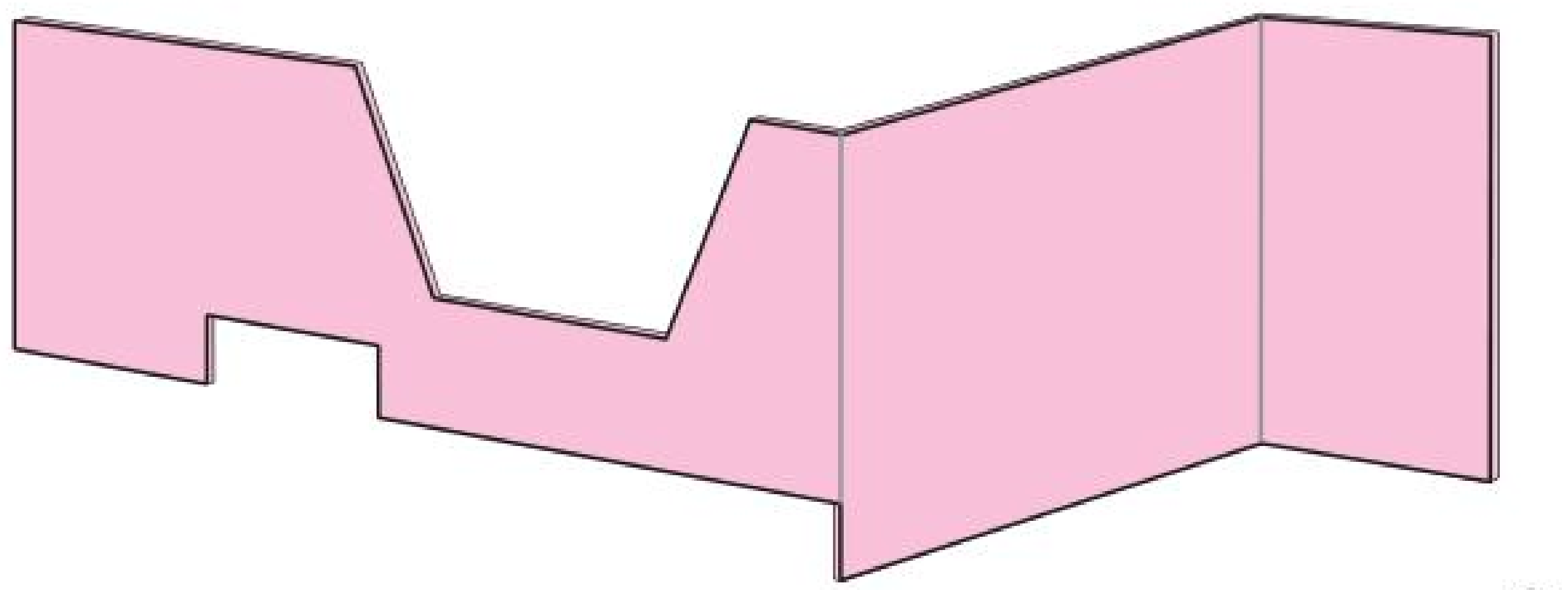


Fig.7: here's how to cut and fold the sheet of insulation material. It forms a physical barrier between the input and output sides.

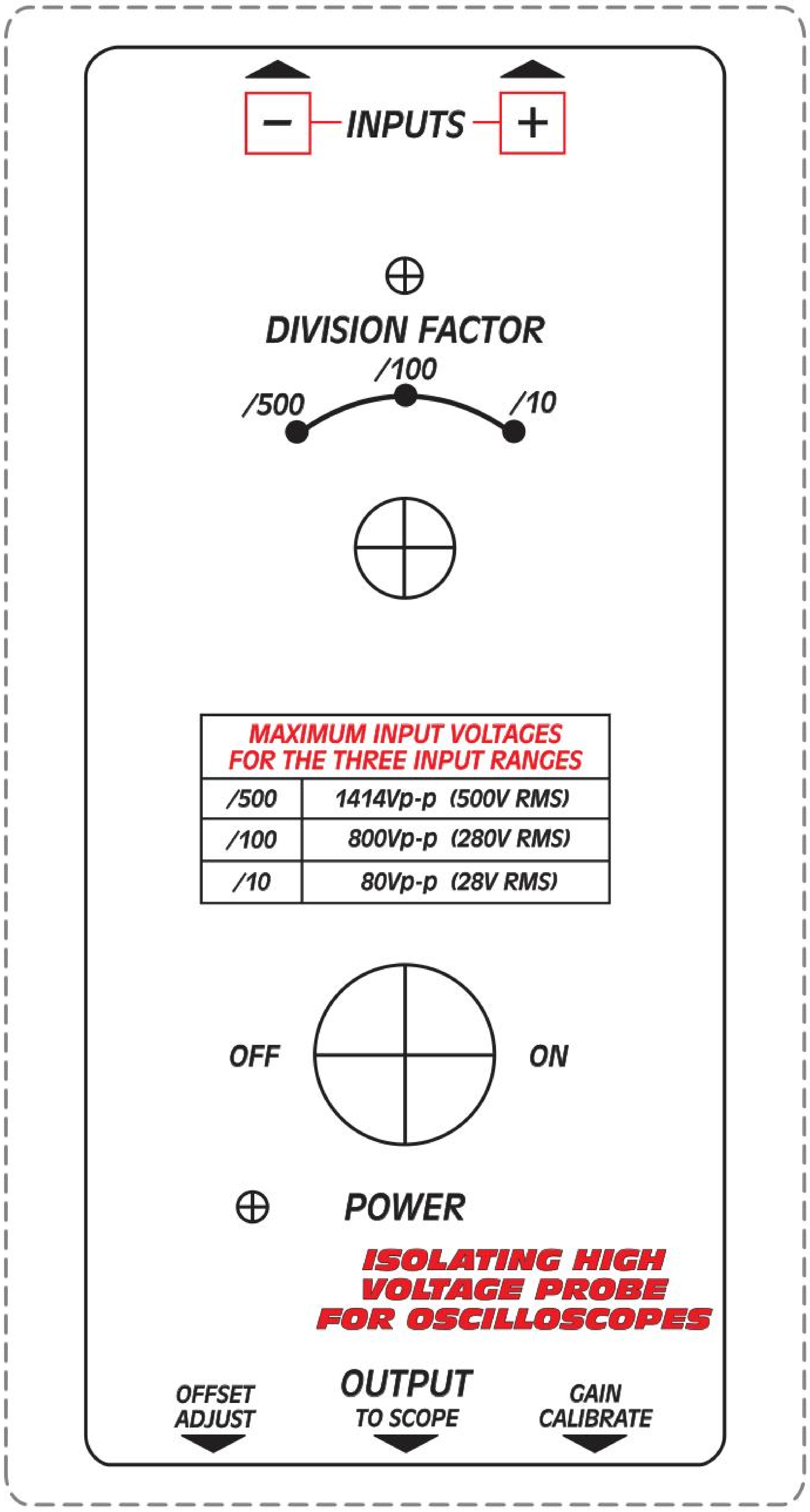


Fig 8: same-size front panel artwork – photocopy this (or download it from epemag.com) and glue it to your box before inserting S2.

When the PCB assembly is secured in place as shown in Fig.6, you'll be able to fit switch S1's spindle with its control knob. Of course you'll also need to solder the wires from S2 to their pads on the PCB, after which you can cut off their excess lengths.

All that remains now is to attach each 9V battery to its snap connector, and then lower it into its waiting 'slot' at the side of the PCB.

The final assembly step is to fit the bottom of the case and fasten it in place with the four 20mm-long countersink head M3 screws supplied with it. However, just before you do this, you'll need to cut off the two PCB mounting spacers moulded into the bottom of the case at the output end.

This is because if left *in situ*, they'll interfere with the heads of the mounting screws on the underside of the PCB. It's not hard to cut off these spacers with a pair of sharp side cutters.

After these 'minor trimming' jobs, you should find that the bottom of the case will mesh nicely with the PCB-and-top assembly, allowing you to fit the four screws holding it all together.

Set-up and calibration

There isn't much involved in setting up and calibrating the probe. The first step is to connect a DMM (set to read DC volts, on its 2V range) to the probe's output connector CON3 using a cable ending in a BNC plug. Now turn range switch S1 to the '/500' position, and also plug two input leads into CON1 and CON2. Connect their far ends together to make sure the probe definitely has 'zero input'.

Next, turn on the probe's power switch S2, and you'll probably see the DMM reading move to a value slightly above or below 0V. The idea now is to adjust trimpot VR2 (Offset Adjust) in one direction or the other with a small screwdriver or alignment tool, to bring the reading as close as possible to 0V.

This is the initial setting for VR2. However, it may have to be readjusted by a small amount after you have performed the second step – calibration.

To calibrate the probe, the simplest approach is as follows. First connect its output (at CON3) to an input of your scope or DSO, using a reasonably short BNC-to-BNC cable. You can adjust the scope's input sensitivity to, say, 1V per division and if it has a switch or option for setting its calibration to allow for a probe's division ratio, set this to the 10:1 position. (This should change the effective input sensitivity to 10V/division.)

Next turn the probe's range switch S1 to the /10 position (fully clockwise) and connect the probe's input leads to a source of moderately low voltage AC.

This can be from an audio generator set to provide a sinewave at about 1kHz with an output level of say 10V RMS (= 28.8Vp-p) or a square wave or function generator set to provide a square wave of again 1kHz at about 20 – 25Vp-p.

Or if you don't have access to either kind of generator, you could use a step-down transformer with a known (ie, measured) secondary voltage of around 12-15V RMS (= 34 – 42.4Vp-p).

When you now turn on the probe's on/off switch (S2), you should see the waveform from your signal source on the scope's display. Its frequency and amplitude should also be displayed if your scope has this facility built in, as most do nowadays.

Now the odds are that while the frequency reading will be correct (either 1kHz or 50Hz as the case may be), the amplitude reading will probably be a little higher or lower than the known level of the signal being fed into the probe.

So what's needed now is to adjust the probe's 'Gain Calibrate' trimpot VR1 in one direction or the other using a small screwdriver or alignment tool, to bring the reading as close as possible to the correct value.

After doing this calibration step, it's a good idea to go back and repeat the first 'Offset Adjust' step – especially if you had to turn VR1 quite a few turns to achieve calibration.

This is done quite easily, simply by removing the probe's input leads from your source of AC and connecting them together. Then after turning the range switch to '/500', you can reconnect the probe's output to your DMM and check what reading you get.

If it has moved slightly away from the '0V' mark, it's simply a matter of adjusting trimpot VR2 to bring it back again. Then your probe will be set up, calibrated and ready for use.

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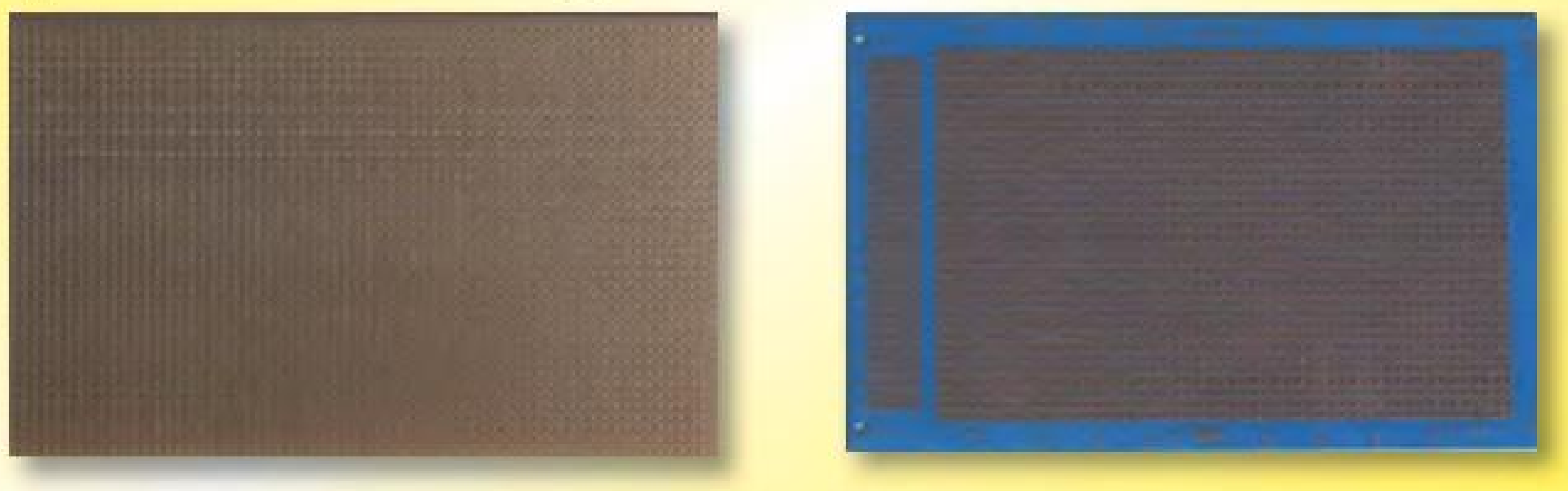

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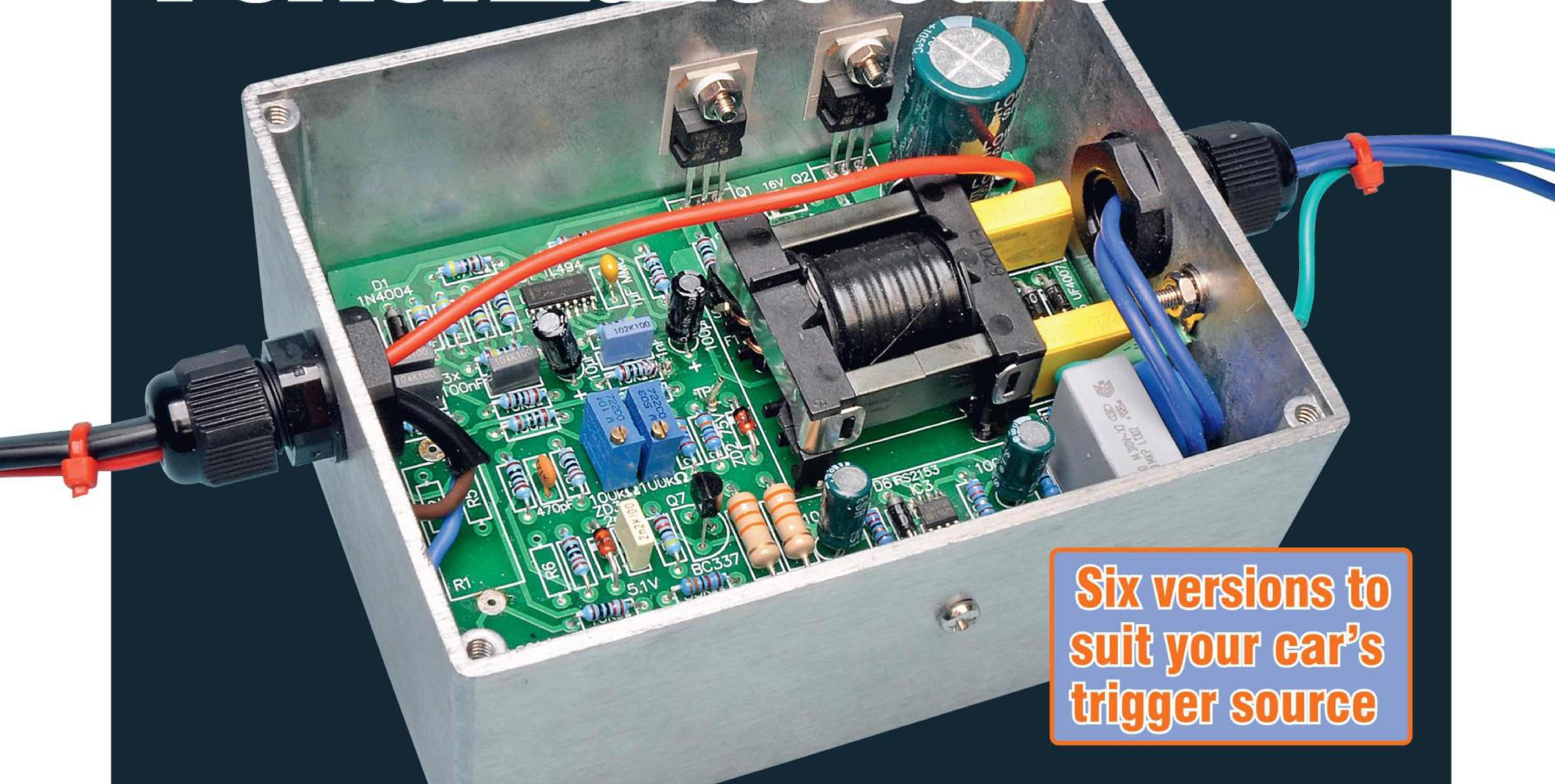
High-Energy Multi-Spark CDI For Performance Cars

Part 2: By JOHN CLARKE



Six versions to suit your car's trigger source

In Part 1 last month, we introduced our new *High-Energy Multi-Spark CDI* and described its operation. In this article, we give the assembly details for six different versions to suit your car's trigger source and describe the installation.

THE ASSEMBLY of the *Multi-Spark CDI* is straightforward, with all parts installed on a double-sided PCB coded 05112141 (110.5 × 85mm). This PCB can be obtained either as part of a complete kit (ie, from parts retailers) or can be purchased from the *EPE PCB Service*.

Fig.5 and Figs.6(a)-6(e) show the parts layouts to suit different ignition pick-up versions. It's simply a matter of building the version to suit the ignition pick-up in your car.

The first step is to install surface mount chips IC1, IC2 and IC3. These are in SOIC packages, so they are not that difficult to solder in place due to their relatively wide 0.05-inch pin spacing. Each IC is mounted on the top of the PCB and must be oriented as shown on Fig.5.

Note that pin 1 is difficult to discern on IC3. However, if you look at the end profile of the IC, there will be a chamfer down one edge. This side has pins 1-4.

To solder an IC in place, you will need a soldering iron with a fine tip and some 'no-clean' flux paste. Begin by carefully placing the IC on top of its pads, ensuring that its orientation and alignment are correct. That done, place a dab of flux paste on one of the corner pins, then put a little solder on the tip of your soldering iron and touch the

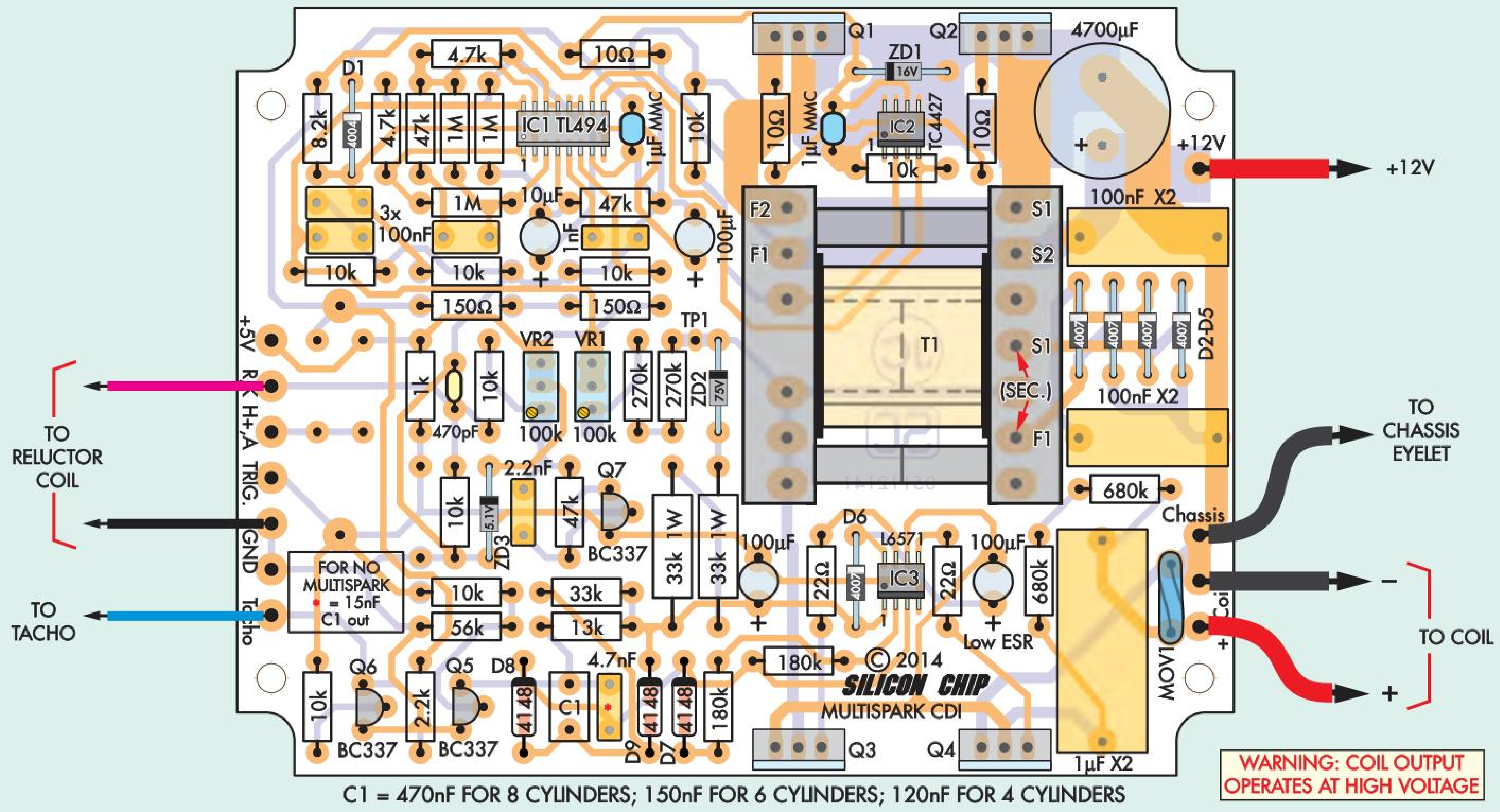

Q1
Q2
4700µF
ZD1
16V
D1
4.7k
10Ω
8.2k
4004
4.7k
47k
1M
1M
IC1 TL494
1µF MMC
10k
10Ω
1µF MMC
IC2
TC4427
10Ω
10k
+12V
+12V
3x 100nF
1M
10µF
1nF
47k
100µF
F2
F1
S1
S2
100nF X2
10k
10k
10k
150Ω
150Ω
TP1
4007
D2-D5
+5V
RX
H+,A
TRIG.
GND
Tacho
TO RELUCTOR COIL
TO TACHO
1k
470pF
10k
VR2
VR1
100k
100k
270k
270k
ZD2
75V
T1
S1
(SEC.)
F1
100nF X2
TO CHASSIS EYELET
2.2nF
Q7
10k
5.1V
ZD3
47k
BC337
33k 1W
33k 1W
680k
Chassis
FOR NO MULTISPARK = 15nF C1 out
10k
56k
33k
13k
100µF
22Ω
D6
L6571
IC3
22Ω
100µF
Low ESR
680k
Coil
TO COIL
Q6
Q5
D8
4.7nF
C1
4148
4148
4148
180k
180k
© 2014
SILICON CHIP
MULTISPARK CDI
10k
2.2k
BC337
BC337
D9
D7
Q3
Q4
1µF X2
MOV1
WARNING: COIL OUTPUT OPERATES AT HIGH VOLTAGE
C1 = 470nF FOR 8 CYLINDERS; 150nF FOR 6 CYLINDERS; 120nF FOR 4 CYLINDERS

Fig.5: follow this PCB layout diagram if your car's distributor has a reluctor pick-up. Be sure to install the three SMD ICs (IC1-IC3) first and note that capacitor C1 must be chosen to suit the number of engine cylinders. Alternatively, leave out C1 and change the adjacent 4.7nF capacitor to 15nF if you wish to disable the multi-spark feature.

pin gently, without disturbing the IC. The flux paste should help 'suck' the solder onto that pin and pad.

Now check the IC's alignment. If it's out, reheat the joint and gently nudge it into place. Once the alignment is good, use the same technique to solder the diagonally-opposite pin.

It's then just a matter of soldering the remaining IC pins and cleaning up any bridges using solder wick. Refresh the joints on the first two pins you soldered, too. Adding no-clean flux paste is recommended for both procedures; when soldering the pins, it reduces the chance of bad joints.

Finally, clean off any excess flux using an appropriate solvent (meths will do in a pinch) and check the joints under magnification to ensure that solder has flowed properly onto every pin and pad.

Once the ICs are in place, the through-hole parts can be installed, starting with the resistors, diodes and zener diodes. Table 1 shows the resistor colour codes, but you should also check each one with a multimeter before fitting it to the PCB.

Be sure to orient the diodes and zener diodes as shown on Figs.5 and 6. The zener diode type numbers are shown in the parts list.

MOSFETs Q1-Q4 are next on the list. These must all be installed so that the tops of their metal tabs are 20-25mm above the PCB. The easiest way to do that is to first loosely fit all the devices in place, then rest the board upside down on 20-25mm-high supports (one at either end). The MOSFET devices can then be pushed down so that their tabs rest against the bench-top and their leads soldered.

Once these parts are in, you can install the capacitors. Note that the electrolytic types must be oriented with the correct polarity (ie, negative lead towards the top edge of the PCB in each case). Note also that the 4700µF and 100µF capacitors must be low-ESR types.

Multi-turn trimpot VR1 can now be fitted. It goes in with its screw adjustment end towards the bottom edge of the PCB (ie, towards Q7).

Transformer winding

Fig.7 shows the transformer details. It's made up by first installing three windings on an ETD29 13-pin bobbin: a 240-turn secondary winding and two primary windings. The bobbin is then fitted to two N87 ferrite cores to complete the assembly.

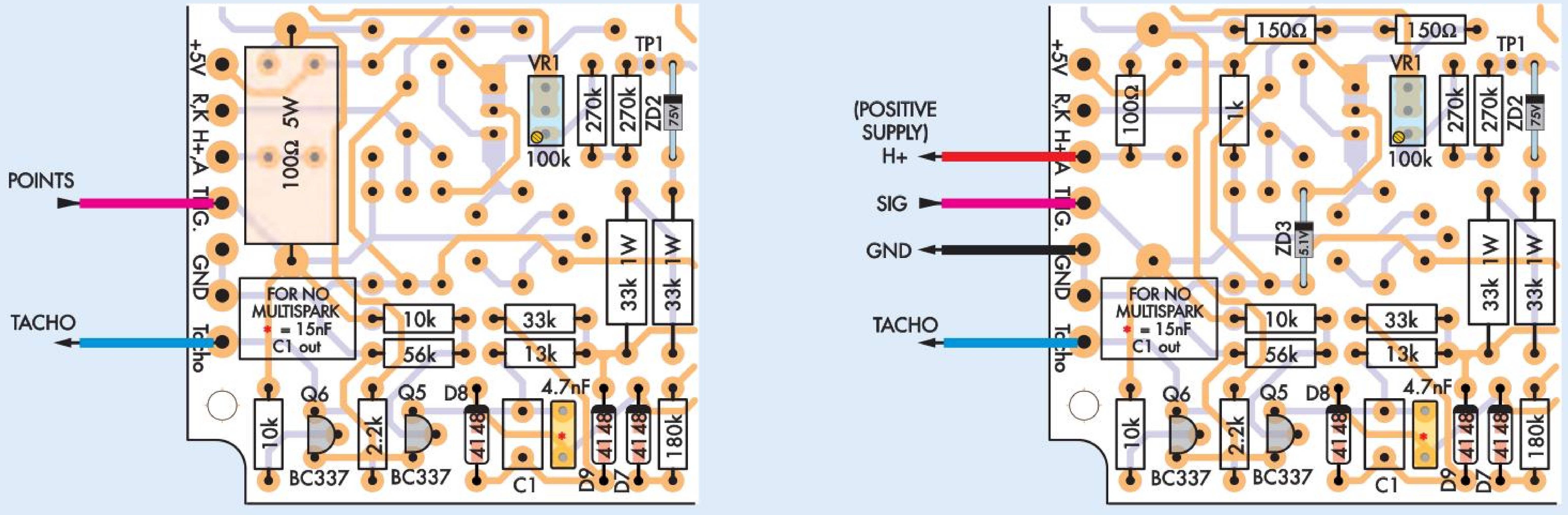
The secondary winding goes on first and is wound using 240 turns of 0.25mm-diameter enamelled copper wire (ECW), about 20m long. The first step is to scrape away about 10mm of the insulation from one end using a sharp hobby knife. This end is then soldered to pin 10 (S1) on the 7-pin side of the bobbin (see Fig.7).

The next step is to wind on four 60-turn layers. Begin by winding the wire clockwise, with the turns placed side-by-side, until the first 60-turn layer is completed. The winding should end

Warning – High Voltage!

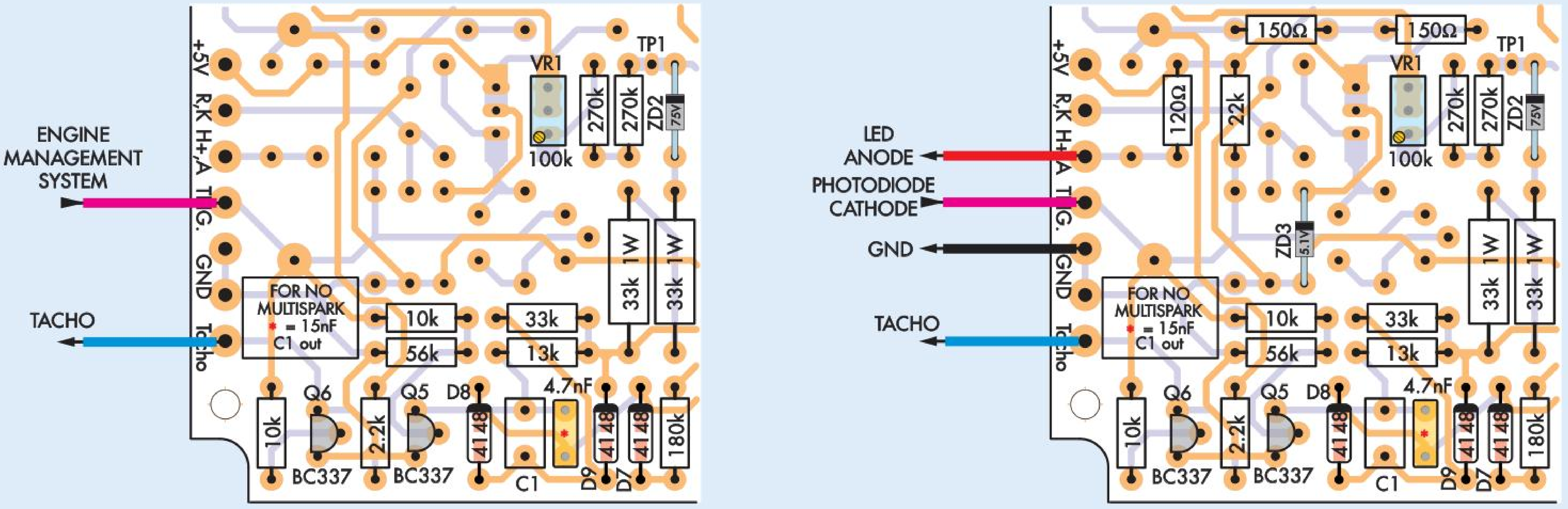
This circuit produces an output voltage of up to 300V DC to drive the coil primary and is capable of delivering a severe (or even fatal) electric shock. DO NOT TOUCH any part of the circuit or the output leads to the coil from CON2 while power is applied.

To ensure safety, the PCB assembly must be housed in the recommended diecast case. This case also provides the necessary heatsinking for the four MOSFETs.


+5V
R,K
H+,A
TG.
GND
Tacho
POINTS
TACHO
100Ω 5W
VR1
100k
TP1
270k
270k
ZD2
75V
33k 1W
33k 1W
FOR NO MULTISPARK
* = 15nF
C1 out
10k
56k
33k
13k
4.7nF
Q6
Q5
D8
10k
2.2k
4148
BC337
BC337
C1
D9
D7
180k
(POSITIVE SUPPLY)
H+
SIG
GND
150Ω
150Ω
100Ω
1k
ZD3
5.1V

(A) POINTS TRIGGERING

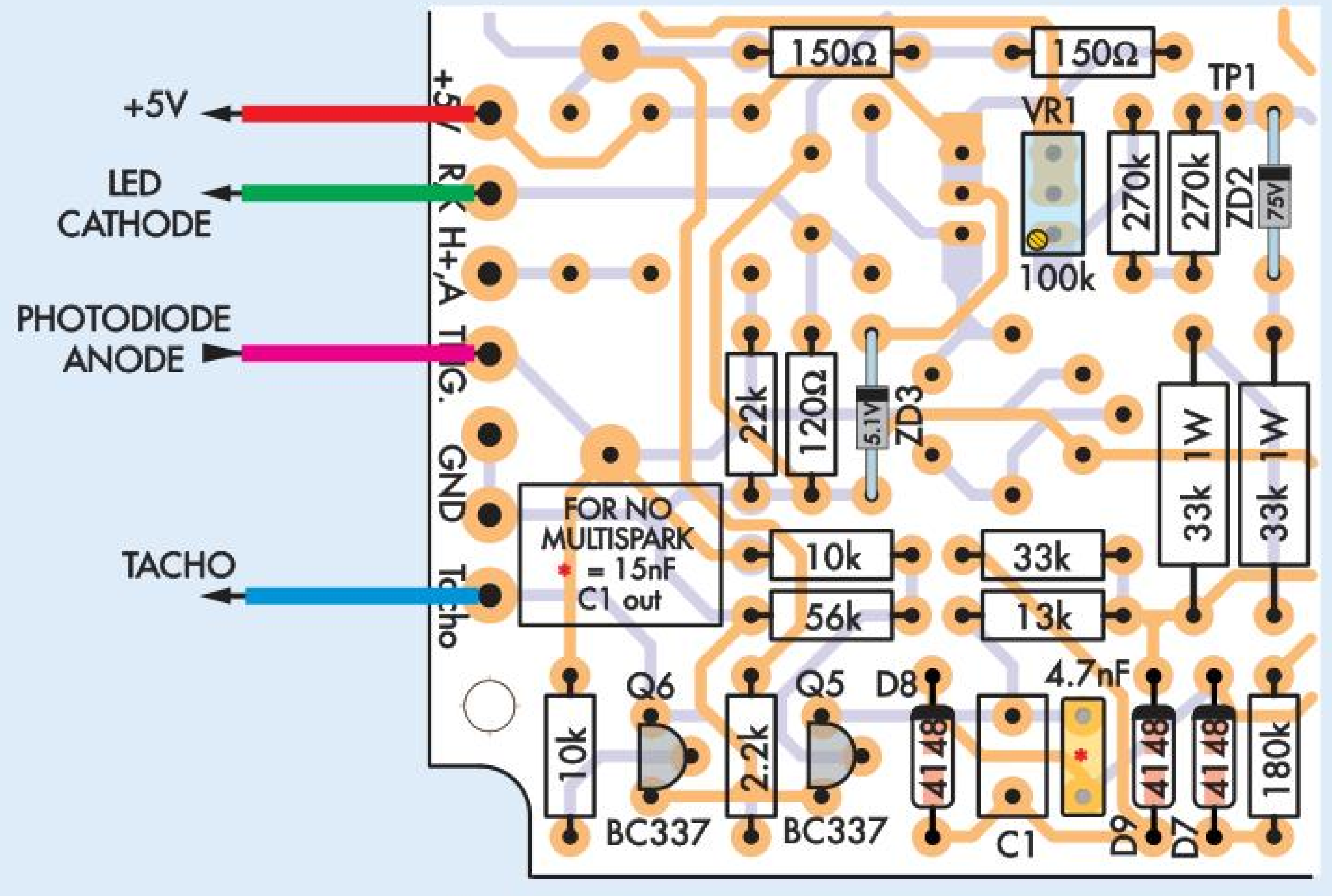
(B) HALL EFFECT OR LUMINITION TRIGGERING


ENGINE MANAGEMENT SYSTEM
TACHO
+5V
R,K
H+,A
TG.
GND
Tacho
VR1
100k
TP1
270k
270k
ZD2
75V
33k 1W
33k 1W
FOR NO MULTISPARK
* = 15nF
C1 out
10k
56k
33k
13k
4.7nF
Q6
Q5
D8
10k
2.2k
4148
BC337
BC337
C1
D9
D7
180k
LED ANODE
PHOTODIODE CATHODE
GND
150Ω
150Ω
120Ω
22k
ZD3
5.1V

(C) ENGINE MANAGEMENT TRIGGERING

(D) CRANE OPTICAL PICKUP TRIGGERING

Fig.6(a)-(e): here's how to mount the parts on the input section of the PCB to suit other ignition trigger types. It's just a matter of choosing the layout to match your car's ignition trigger and then mounting the remainder of the parts as shown on Fig.5. Note that the 100Ω 5W resistor used in the points triggering version should be secured to the PCB using neutral-cure silicone, to prevent it from vibrating and fracturing its leads and/or solder joints.


+5V
LED CATHODE
PHOTODIODE ANODE
TACHO
+5V
R,K
H+,A
TG.
GND
Tacho
150Ω
150Ω
VR1
100k
TP1
270k
270k
ZD2
75V
22k
120Ω
5.1V
ZD3
33k 1W
33k 1W
FOR NO MULTISPARK
* = 15nF
C1 out
10k
56k
33k
13k
4.7nF
Q6
Q5
D8
10k
2.2k
4148
BC337
BC337
C1
D9
D7
180k

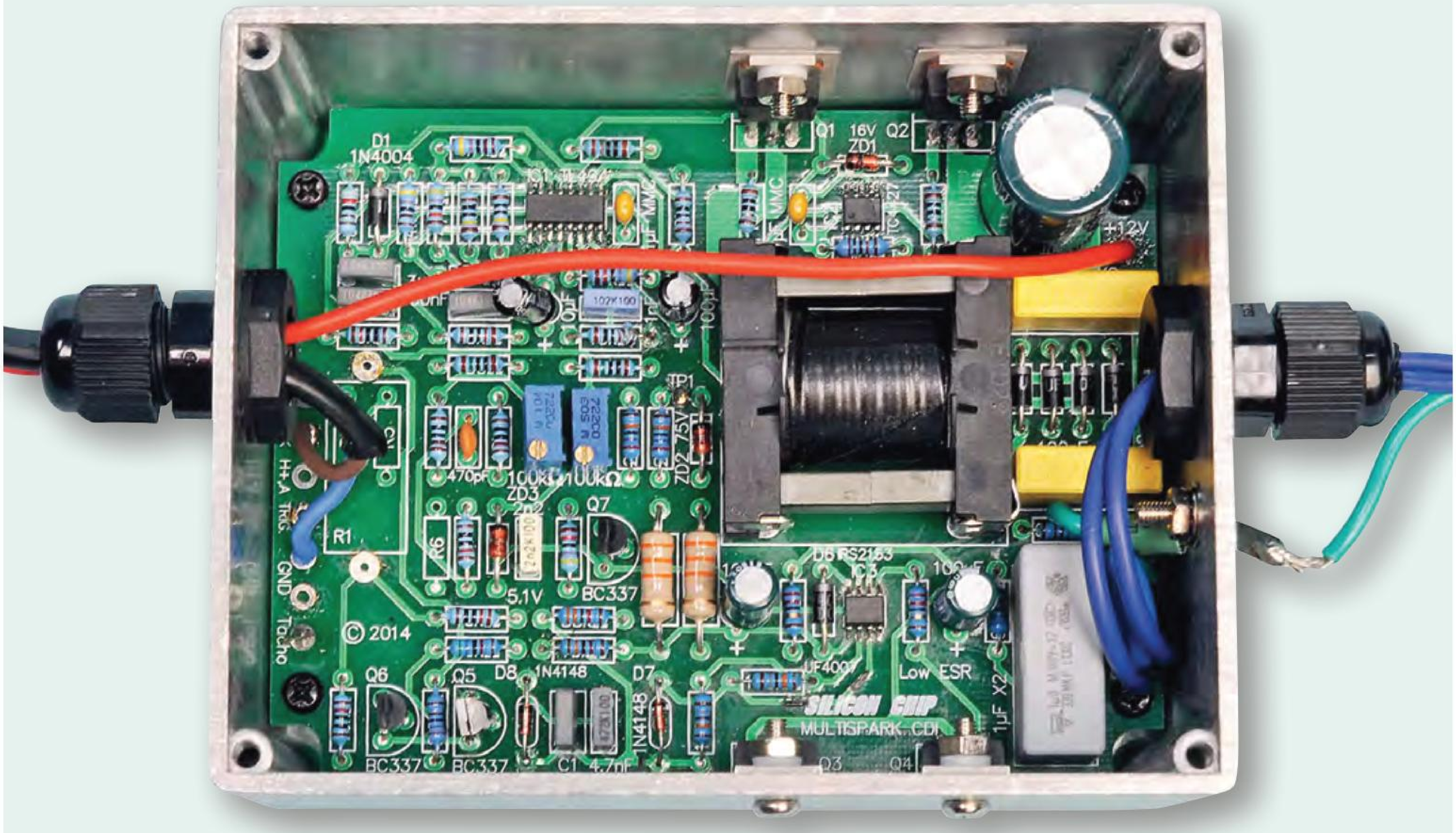
(E) PIRANHA OPTICAL PICKUP TRIGGERING

up near the edge of the bobbin on the opposite side to the S1 start pin.

Cover this winding with a single layer of insulation tape, taking care to also cover the start of the wire as it comes down from the bobbin pin. The next 60-turn layer can then be wound on in the same clockwise direction, again with the wires close-wound and laid side-by side. Cover this winding with another single layer of tape, then complete the other two 60-turn layers in exactly the same manner, finishing with another layer of tape.

The end of the winding is now trimmed, stripped of insulation and soldered to pin 8 (F1), as shown. As before, make sure that the wire end is covered with a layer of insulation tape as it exits from the bobbin to connect to the pin. The idea is to make sure that the secondary winding will be electrically isolated from the primary windings.

The primary windings are wound using two separate 600mm lengths of 1mm ECW. Start by scraping about 10mm of insulation from one end of each wire, then wrap and solder them to pins 13 and 12 on the bobbin.


D1
1N4004
Q1
16V
ZD1
Q2
+12V
R1
Trig
GND
Tacho
470pF
100kΩ
ZD3
Q7
BC337
5.1V
ZD2 75V
TP1
© 2014
Q6
Q5
D8
1N4148
D7
BC337
C1 4.7nF
D6 IRS2183
IC3
UF4007
Low ESR
SILICON CHIP
MULTISPARK CDI
Q3
Q4

This inside view shows the completed *High-Energy Multi-Spark CDI* with the parts installed for a reluctor pick-up trigger (see Fig.5). Be sure to use heavy-duty automotive cable for the external wiring connections.

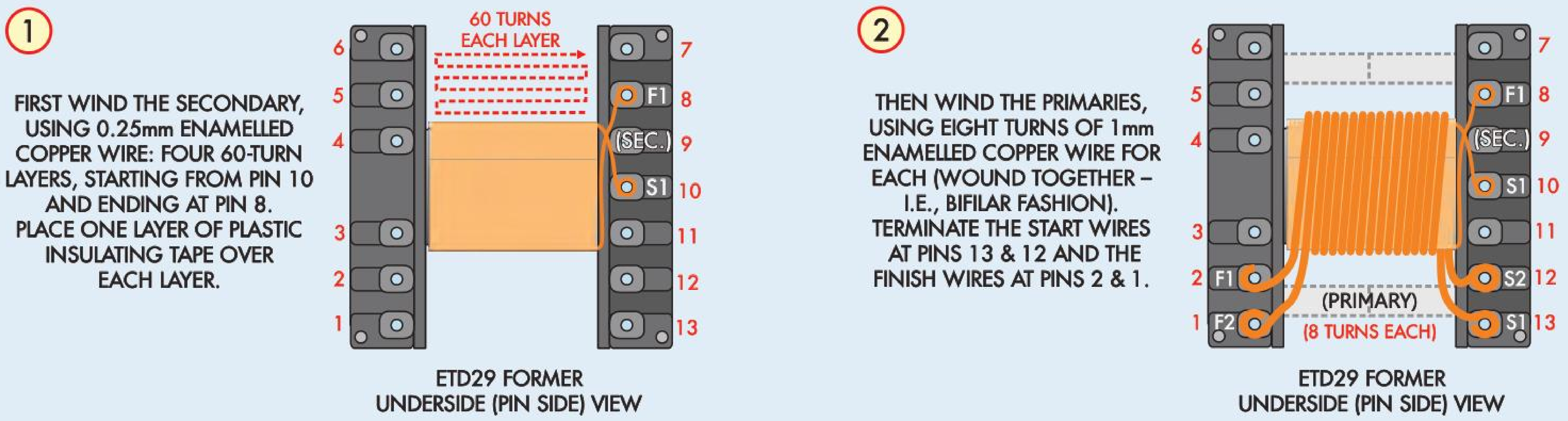

①
FIRST WIND THE SECONDARY, USING 0.25mm ENAMELLED COPPER WIRE: FOUR 60-TURN LAYERS, STARTING FROM PIN 10 AND ENDING AT PIN 8. PLACE ONE LAYER OF PLASTIC INSULATING TAPE OVER EACH LAYER.
60 TURNS EACH LAYER
6
5
4
3
2
1
7
F1 8
(SEC.) 9
S1 10
11
12
13
ETD29 FORMER UNDERSIDE (PIN SIDE) VIEW
②
THEN WIND THE PRIMARIES, USING EIGHT TURNS OF 1mm ENAMELLED COPPER WIRE FOR EACH (WOUND TOGETHER – I.E., BIFILAR FASHION). TERMINATE THE START WIRES AT PINS 13 & 12 AND THE FINISH WIRES AT PINS 2 & 1.
6
5
4
3
2 F1
1 F2
7
F1 8
(SEC.) 9
S1 10
11
S2 12
S1 13
(PRIMARY)
(8 TURNS EACH)
ETD29 FORMER UNDERSIDE (PIN SIDE) VIEW

Fig.7: the winding details for transformer T1. The secondary is wound first using four 60-turn layers of 0.25mm-diameter enamelled copper wire (ECW), starting and finishing at pins 10 and 8. The primary is then wound on using eight bifilar turns of 1mm-diameter ECW, starting at pins 13 and 12 and finishing at pins 2 and 1 respectively.

The two primary windings are now wound on together (ie, bifilar wound). It's just a matter of winding on eight turns and then connecting the wire ends to pins 1 and 2. Note that the wire that starts at S1 (pin 13) must connect to F1 (pin 2), while the wire from S2 (pin 12) must connect to F2 (pin 1).

You can identify the windings using a multimeter. There should be close to 0Ω between S1 and F1 and close to 0Ω between S2 and F2. Conversely, there should be high impedance (>1MΩ) between S1 and S2, and between the two primary windings and the secondary.

Once the primary has been completed, cover this winding with a single layer of insulation tape cut to fit the inside width of the bobbin. It's then just a matter of sliding the two ferrite cores into the bobbin and securing them in place using the supplied clips.

The transformer assembly can now be installed on the PCB. It can only go in one way, since one side of the bobbin has six pins while the other has seven. Be sure to push the transformer all the way down onto the board before soldering its pins.

The PCB assembly can now be completed by soldering long lengths of heavy-duty automotive cable to the PCB wiring points for the +12V supply, trigger inputs, coil connections and tacho connection. The chassis connection (near the coil connections) goes to a solder lug that's secured to the case, so this lead can be kept short.

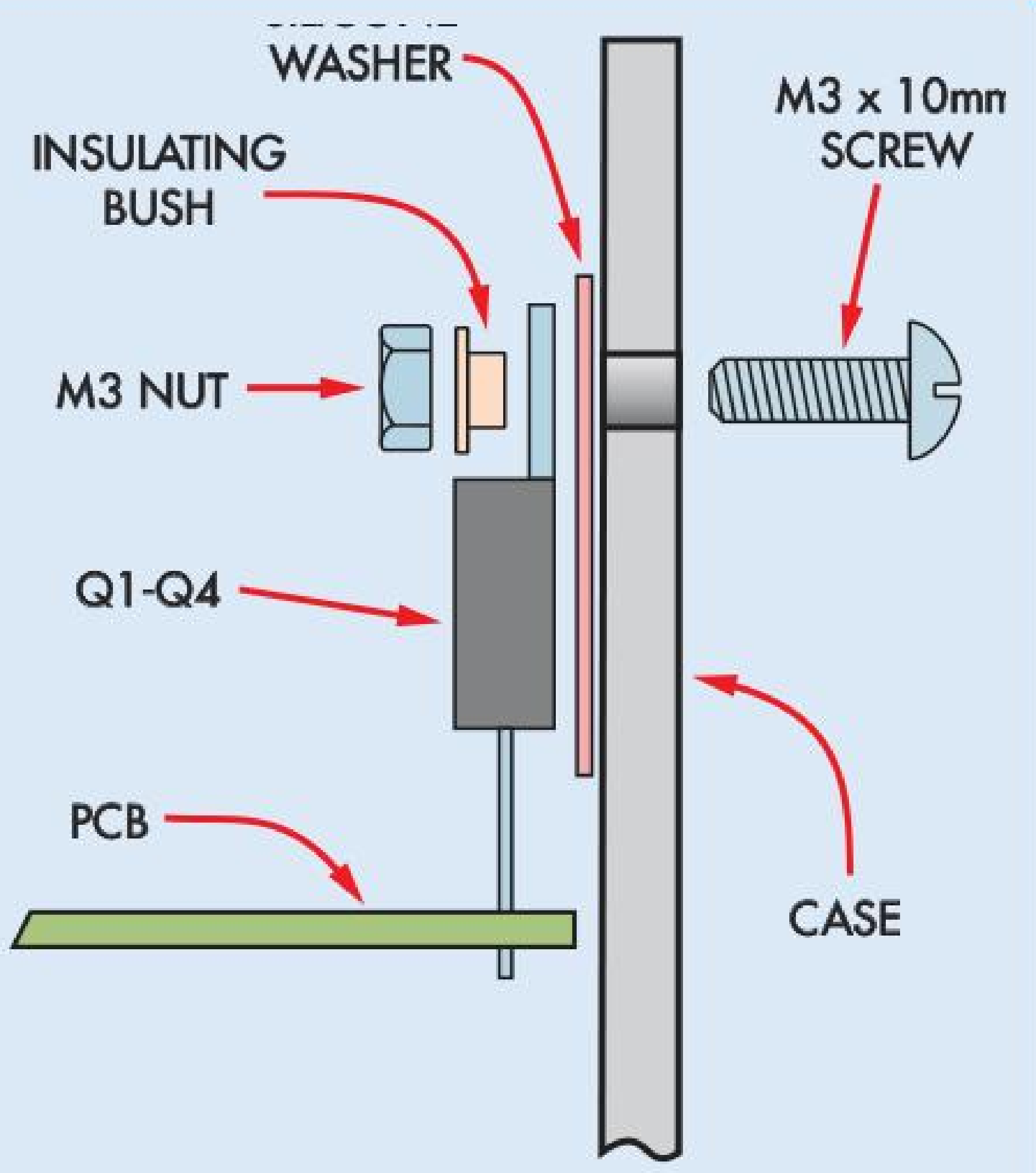


Fig.8: the mounting details for MOSFETs Q1-Q4. The metal tab of each device must be insulated from the case using an insulating bush and silicone washer. Do the mounting screws up firmly, then use a DMM to make sure each tab is indeed insulated from the case.

Preparing the case

The completed PCB assembly is housed in a diecast metal case measuring 119 × 94 × 57mm. This has to have a number of holes drilled in order to mount the PCB, secure the tabs of Q1-Q4 and fit cable glands.

Start the case preparation by drilling the PCB mounting holes. To do this, first place the PCB assembly inside the case and mark out the four corner holes in the base. That done, remove the PCB, drill these holes out to 3mm diameter and remove any burrs using an oversize drill. These holes should then be countersunk on the outside of the case, to accept M3 countersink head screws.

Next, secure four M3 × 9mm tapped spacers to the PCB mounting holes using M3 × 6mm pan-head screws, reposition the PCB inside the case and mark out the tab mounting hole positions for Q1-Q4. Drill these out to 3mm diameter and lightly countersink them using an oversize drill to remove any sharp edges on the holes. This step is vital to prevent the insulating washers that fit between the MOSFET tabs and the case from being punctured.

Next, drill a 3mm hole in the side of the case so that the earth solder lug can be attached. This lug can then be installed using an M3 x 6mm machine screw, nut and shakeproof washer.

Holes are also required in the left-hand and righthand ends of the case to accept the two specified cable glands. These two 15mm-diameter holes should be located 15mm down from the top of the case and 50mm in from the rear. You can drill the cable gland holes in one step using a 15mm Irwin Speedbor drill.

Alternatively, use a small pilot drill to start the holes, then carefully enlarge them to size using a tapered reamer. Remove any sharp edges and metal swarf using a rat-tail file.

Once all the holes have been drilled, install the PCB in the case and secure the spacers to the base using four M3 × 6mm countersink-head screws fed up through the base. MOSFETs Q1-Q4 can then be fastened to the sides of the case, as shown in Fig.8. In each case, this involves using a silicone washer and insulating bush to electrically isolate the device tabs from the case. Secure each tab assembly to the case using an M3 × 10mm machine screw and nut. You can also fit a shakeproof washer if you wish.

Now check that the tab of each device is indeed electrically isolated from the case. That's done simply by measuring the resistance between the case and each MOSFET tab using a multimeter. Each device should give a very-high-ohms reading, although the reading may initially be low and then quickly increase as the capacitors charge up via the multimeter's leads.

A permanent low-ohms reading means there is a short between the tab of that particular device and the case. If that happens, undo the assembly, clear the fault (eg, metal swarf or a sharp edge on the mounting hole) and replace the silicone washer with a new one.

Finally, trim and solder the chassis wire to the earth lug and attach it to the side of the case.

The +12V lead should be fed through the left cable gland along with the trigger wires. The two ignition coil wires should pass through the right hand cable gland. Be sure to use heavy-duty automotive cable for all these connections, and lace the wiring securely to ensure reliability.

Note that running the +12V lead through the same clamp as the ignition

Table 2: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
100nF	0.1µF	100n	104
4.7nF	.0047µF	4n7	472
1nF	0.001µF	1n	102

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	3	1MΩ	brown black green brown	brown black black yellow brown
☐	2	680kΩ	blue grey yellow brown	blue grey black orange brown
☐	2	270kΩ	red violet yellow brown	red violet black orange brown
☐	2	180kΩ	brown grey yellow brown	brown grey black orange brown
☐	1	56kΩ	green blue orange brown	green blue black red brown
☐	2	47kΩ	yellow violet orange brown	yellow violet black red brown
☐	3	33kΩ	orange orange orange brown	orange orange black red brown
☐	1	13kΩ	brown orange orange brown	brown orange black red brown
☐	7	10kΩ	brown black orange brown	brown black black red brown
☐	1	8.2kΩ	grey red red brown	grey red black brown brown
☐	2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
☐	1	2.2kΩ	red red red brown	red red black brown brown
☐	2	22Ω	red red black brown	red red black gold brown
☐	3	10Ω	brown black black brown	brown black black gold brown

coil would induce high voltage spikes into the +12V supply, so don't do this.

Testing

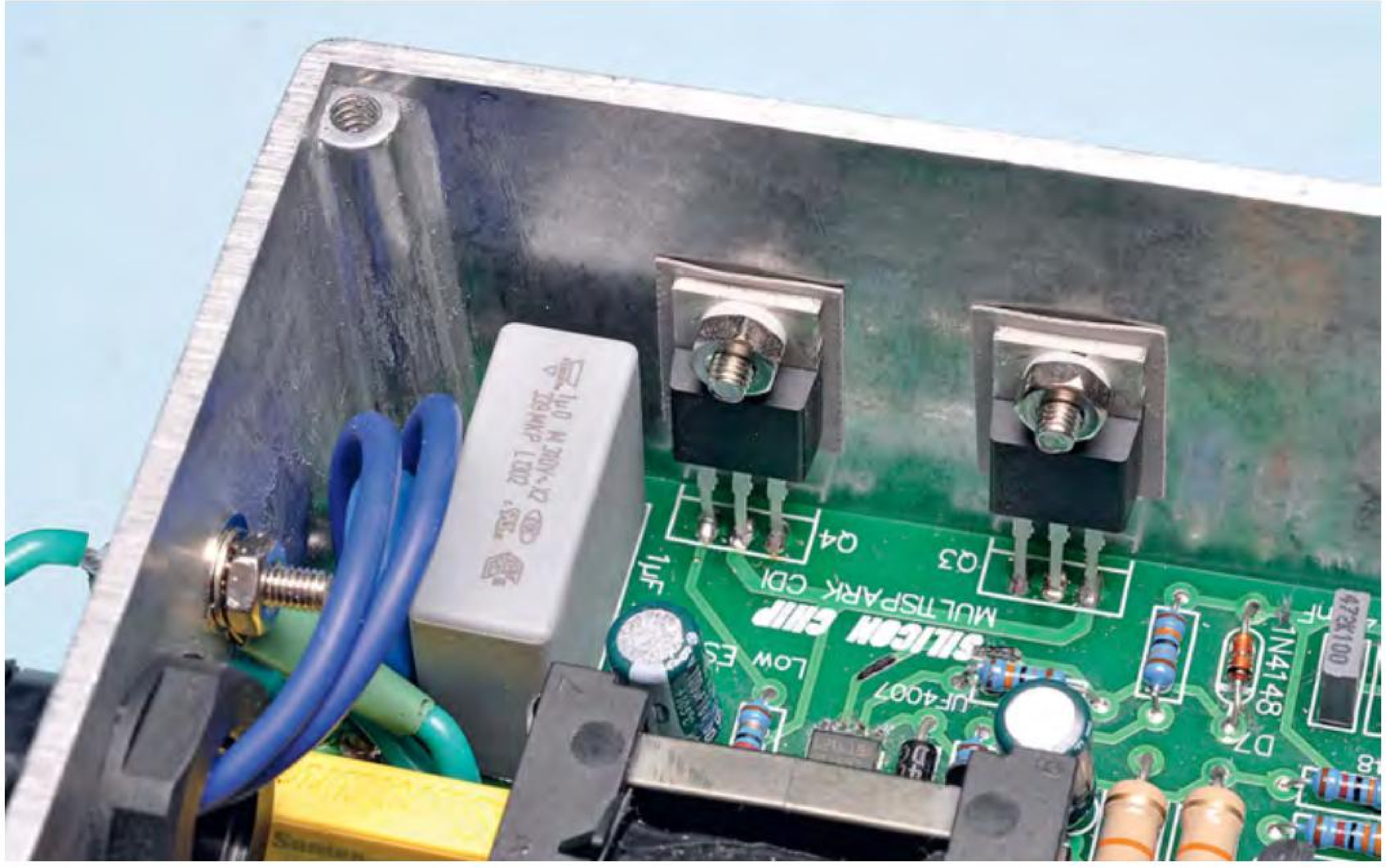
If possible, use a current-regulated power supply to initially test the DC-DC converter in the *Multi-Spark CDI* unit. **And here a word of warning: this inverter produces around 300V DC, so don't touch any part of the circuit while it is operating. For the same reason, it's important not to touch the output wires to the coil.**

Before applying power, it's a good idea to fit the lid on the box. Electrolytic capacitors have a nasty habit of exploding if they are installed with reverse polarity, so this simple step will protect your eyes. At the very least, wear eye protection if you intend operating the unit with the lid off.

If everything is OK when power is applied, then power off again and remove the lid. VR1 now has to be adjusted to set the converter's output to 300V. To do this, connect a multimeter between the chassis and test point TP1, then reapply power and adjust VR1 for a 300V DC reading **(be careful not to touch any part of the circuit).**

For a reluctor pick-up, VR2 has to be adjusted so that the pick-up sensitivity is correct. That's done as follows:

1) Connect the reluctor to the CDI.
2) Turn VR2's adjustment screw anticlockwise by 10 turns, then adjust this screw clockwise until Q7's collector drops to 0V.
3) Turn VR2's adjustment screw anticlockwise so that Q7's collector just goes to about 5V, then adjust VR2 anticlockwise by two more turns (this ensures that Q7 is not prone to switching on and off with no reluctor signal).



This view shows how MOSFETs Q3 and Q4 are secured to the case for heat-sinking. Make sure that their case mounting holes are free of any metal swarf before installing the insulating washers and mounting screws. MOSFETs Q1 and Q2 are mounted in similar fashion (see Fig.8).

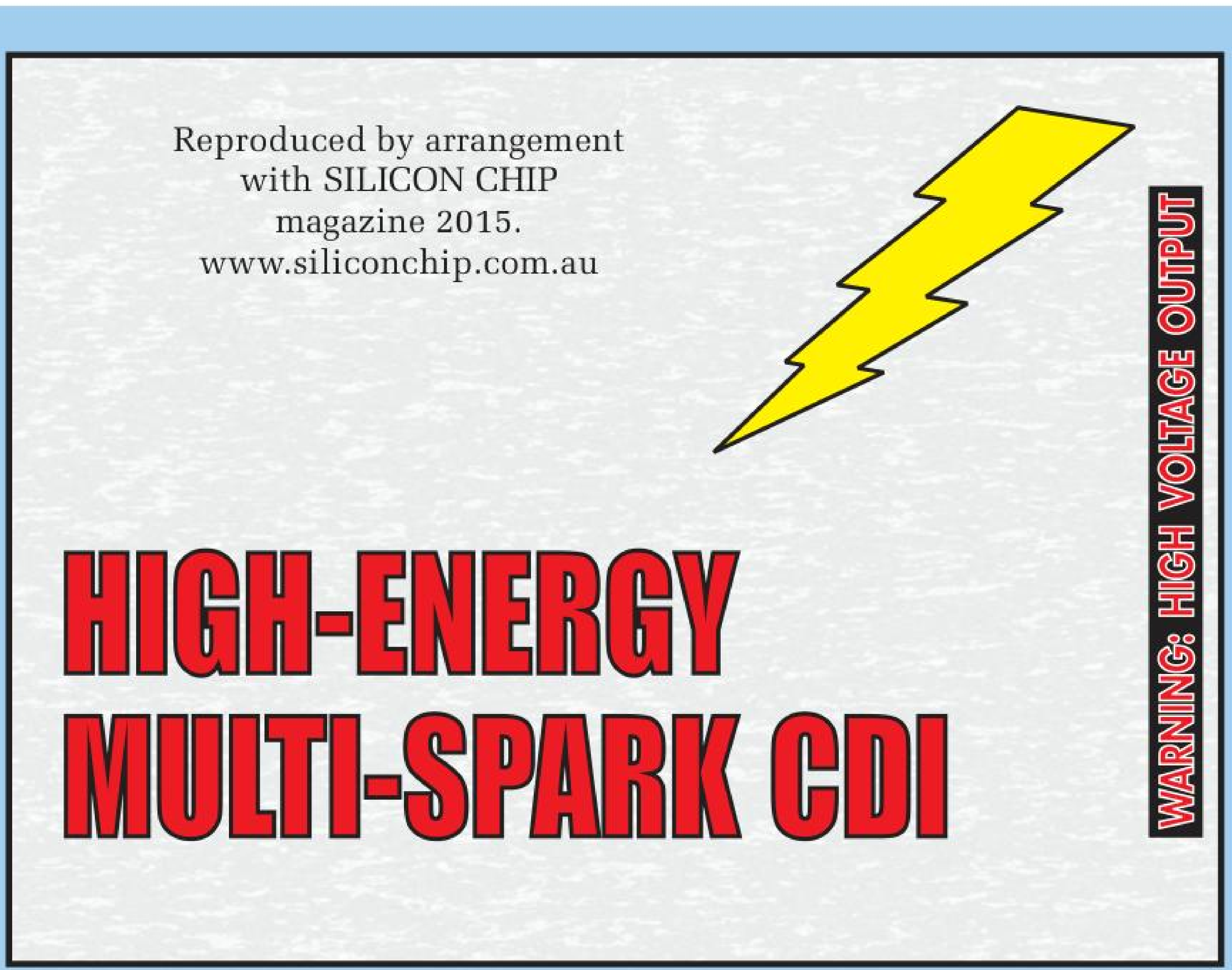

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Fig.9: the front panel artwork can be downloaded from the *EPE* website, printed out and sandwiched between the case lid and a perspex sheet. Use neutral cure silicone to secure the perspex in place.

Installation

Be sure to mount the CDI case in a splash-proof location where air flows over it and make sure that it is well away from the exhaust side of the engine. It can be secured inside the engine bay using self-tapping screws or you could use brackets. Make sure that the case is well-earthed to the vehicle chassis.

Once it's in place, connect the positive supply lead to the +12V ignition line and the trigger input to the ignition pick-up. The coil leads go to either side of the ignition coil primary. Disconnect any other wires that are part of the original ignition system. The tacho signal leads runs direct to the tachometer (again, disconnect the existing signal lead).

Note that a reluctor coil pick-up must be connected with the correct polarity in order to give the correct spark timing. This is best determined by testing the engine. If it doesn't fire, reverse the leads and try again.

You may find that with the *Multi-Spark CDI* installed, the spark timing is a little advanced, due to the CDI's fast rise time. If so, you may need to retard the static timing slightly to prevent pinging or a slightly rough idle.

Note that it's always a good idea to turn the ignition on for one or two seconds before actually cranking the engine. This will allow IC3's 100µF filter capacitor to fully charge and give the inverter circuit sufficient time to generate its 300V DC output.

Once it's all working, use neutral cure silicone to seal the lip of the case, the cable glands and any mounting screws. This will ensure that the case is watertight and ensure reliability.

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Currawong
Currawong
Valve Amplifier

By Nicholas Vinen

The Currawong

2 x 10W Stereo Valve Amplifier – Part 3

In the last two instalments, we introduced the *Currawong Valve Amplifier*, described its circuit and gave the PCB assembly and wiring details. This final article describes the optional remote volume control, the acrylic cover and the setting-up procedure.

YOU DON'T HAVE to build the remote volume control board, but we think most constructors will want to. It's just so convenient when it comes to setting the volume and is far easier than having to wander over to to wind the volume control up or down.

If you intend building the remote control into the *Currawong*, you should have already fitted the motorised pot to the main board. The 50 × 50mm remote board hangs from the front-right corner of the main PCB via a tapped spacer and is connected via a 4-pin header. There is also a connection from the remote control board to the pot motor.

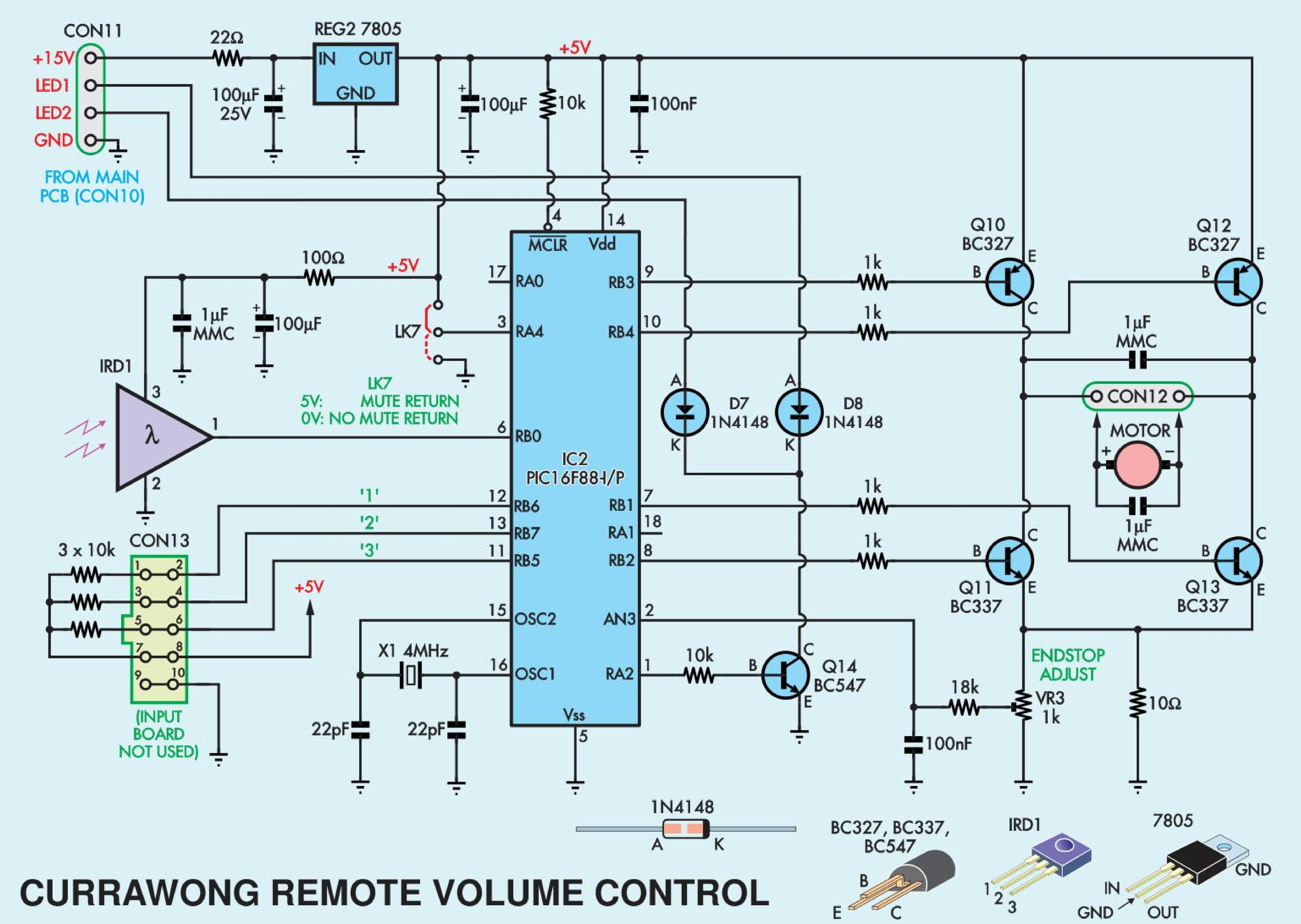
If you aren't fitting the remote control option to your *Currawong Amplifier*, skip down to the 'Initial power up and testing' cross-heading below.

IR remote control circuit

The remote control circuit is shown in Fig.12. It works as follows. The remote control is set to generate Philips RC5 protocol codes which are picked up by infrared receiver module IRD1. Its output goes to pin RB0/INT on PIC16F88 microcontroller IC2. IC2 decodes the remote commands and if it detects a relevant code (volume up/down/mute), it then uses its RB1-RB4 output pins to drive transistors Q10-Q13 which are arranged in an H-bridge configuration, to drive the pot motor in the appropriate direction.

A 1µF capacitor is connected across the motor terminals on the PCB to reduce hash from the motor brushes; there is also a capacitor soldered directly across the motor terminals, at the other end of the figure-8 wire from CON12.

IC2 monitors the motor current across a 10Ω shunt resistor. The


CON11
+15V
LED1
LED2
GND
FROM MAIN PCB (CON10)
22Ω
100µF 25V
REG2 7805
IN
OUT
GND
+5V
100µF
10k
100nF
100Ω
1µF MMC
100µF
IRD1
λ
LK7
LK7
5V: MUTE RETURN
0V: NO MUTE RETURN
IC2 PIC16F88-I/P
MCLR
Vdd
RA0
RA4
RB0
RB6
RB7
RB5
OSC2
OSC1
RB3
RB4
RB1
RA1
RB2
AN3
RA2
Vss
'1'
'2'
'3'
3 x 10k
CON13
(INPUT BOARD NOT USED)
X1 4MHz
22pF
22pF
D7 1N4148
D8 1N4148
A
K
1k
10k
Q10 BC327
Q12 BC327
Q11 BC337
Q13 BC337
Q14 BC547
1µF MMC
CON12
MOTOR
ENDSTOP ADJUST
18k
VR3 1k
100nF
10Ω
1N4148
BC327, BC337, BC547
B
E
C
IRD1
1
2
3
7805
IN
GND
OUT
GND

CURRAWONG REMOTE VOLUME CONTROL

Fig.12: the circuit for the add-on remote volume control. The infrared signal is received by infrared receiver IRD1 and passes to microcontroller IC2, which decodes it and uses Q10-Q13 to drive the pot motor in the required direction. Power comes from the main board.

feedback voltage is adjusted using pot VR3 and goes through a low-pass RC filter (18kΩ/100nF) before being fed to analogue input AN3 on IC2. IC2 can thus detect the increase in current when the pot hits one of its end-stops.

This feedback is used for the mute function. When mute is pressed, the motor is driven anti-clockwise until the pot hits its minimum end-stop. IC2 detects the increase in current and shuts the motor off once minimum volume has been reached. If mute is then pressed again and LK7 is in the high position, the motor is driven clockwise for the same time as it took to reach the end-stop, thus returning the pot to the original volume level.

For this to work, VR3 must be adjusted correctly. If it's set too high, the motor may stop prematurely, but if set too low, the motor may not stop once minimum volume has been reached.

In this design, IC2 flashes an acknowledge LED to indicate when a valid remote control command is received. We have used output RA2 to drive NPN transistor Q14, which pulls the cathodes of small-signal diodes D7 and D8 low in acknowledgement. These go to either end of red/green LED1 on the main board via pin header CON11. As a result, when a command is received, LED1 is shorted out and so it flashes off briefly. This avoids the need for an extra LED to be fitted for the remote control function.

PIC microcontroller IC2 uses 4MHz crystal X1 for time-keeping. This is required as the remote control commands are sent at a particular frequency and the micro needs to be able to 'lock on' to these commands to properly decode them.

Multiple input option

We are using a 10-pin header CON13, which enables the possibility of fitting multiple inputs to the *Currawong* and having remote-controlled switching. This would require the main *Currawong* board to be built into a larger case with enough room for the extra inputs and the relay board required.

In the standard *Currawong* design, (ie, no input switching), we just connect 10kΩ pull-up resistors from pins 7 and 8 (+5V) to pin pairs 1/2, 3/4 and 5/6 as shown so that the unit will

Transformer bolt earthing – WARNING!

Note that the mounting bolts for the mains transformers T1 and T2 **must not be separately earthed** (ie, via earth leads) if the amplifier is mounted in a metal chassis. That's because running earth leads to them would result in a shorted turn on each transformer and this would immediately blow the fuse in the IEC socket.

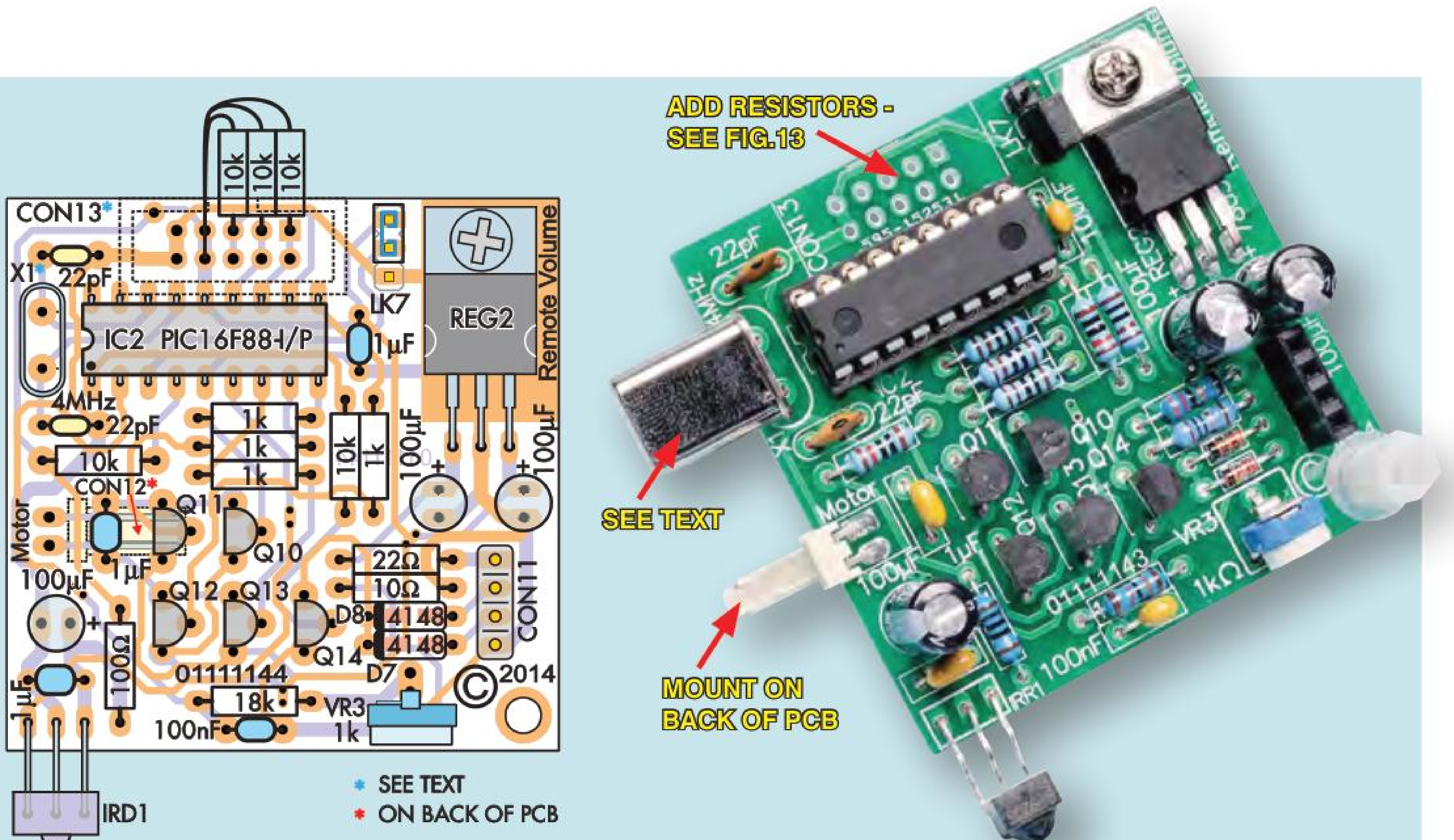


Fig.13: follow this parts layout diagram to build the remote volume control PCB. This sits just below the main board, so the available component height is limited. As a result, motor header CON12 and crystal X1 (if full height) must be fitted at right angles on the underside of the PCB (not on top as shown in the photo). In addition, the electrolytic capacitors should be pushed all the way down to the board before soldering or else bent over so that they will later clear the main board assembly.

function without the input switching board connected.

Power for the remote control unit is derived from the *Currawong's* unfiltered low-voltage DC rail of around 15V via pins 1 and 4 of CON11. This supply goes through a low-pass RC filter (22Ω/100µF) before being fed to a standard 5V regulator, REG2.

The 5V output from REG2 is used to power the micro and the motor, but is further filtered using a 100Ω resistor and 100µF capacitor for infrared receiver IRD1 (plus an extra 1µF ceramic bypass capacitor) in order to prevent motor hash from interfering with infrared command reception.

Remote PCB assembly

The remote control PCB is available from the *EPE PCB Service*, coded 01111144. The parts layout is shown in Fig.13. Start by fitting the two diodes, cathode stripe to the left, then follow with the resistors. You can check their striped bands against the resistor colour code table (Table 3). However, it's also a good idea to measure them with a DMM because the colours can be hard to read clearly.

Note that while most of the resistors are laid flat in the traditional manner, the three 10kΩ resistors soldered to the pads for CON13 will need to be fitted vertically, with two leads sharing one of the holes. We used mini 0.25W resistors here, since they fit more easily.

Solder the IC socket in place next, with its notched end to the left, followed by REG2. Prepare the regulator by first bending its leads down through 90° about 6mm from the tab, then attach the tab to the PCB using an M3 × 6mm machine screw and nut. Make sure the screw is done up tightly before soldering and trimming the leads.

The ceramic capacitors can go in next; their polarity does not matter. You will be left with a 1µF type to be soldered across the motor terminals later.

Follow with the small-signal transistors, taking care to avoid getting the three types mixed up. Crank their leads out to fit the PCB pads using small pliers. **If you have a low-profile 4MHz crystal, this can be fitted to the top of the board, as shown in Fig.13. Otherwise, you will need to cover the metal can with a short length of 10mm diameter heatshrink tubing, shrink it down, bend the leads through 90° and fit it to the underside of the board so that it's laying horizontally under PIC micro IC2.** In this case, solder its leads on the top side of the board.

Note that in our photos, X1 is shown bent over to the left, but this was found to interfere with the mains power switch when the board was in place, so we later moved it to the underside and bent it in the other direction, as described above.

The right-angle polarised header for the motor is also mounted on the underside of the board, with its pins facing the righthand edge, for the same reason (again, shown differently in the photo). Solder its pins on the top side.

The 3-pin header for LK7 and 4-pin header socket CON11 are fitted as usual, to the top side of the board. Put the shorting block over LK7 in the position shown for mute return or fit it in the alternative position to disable mute return.

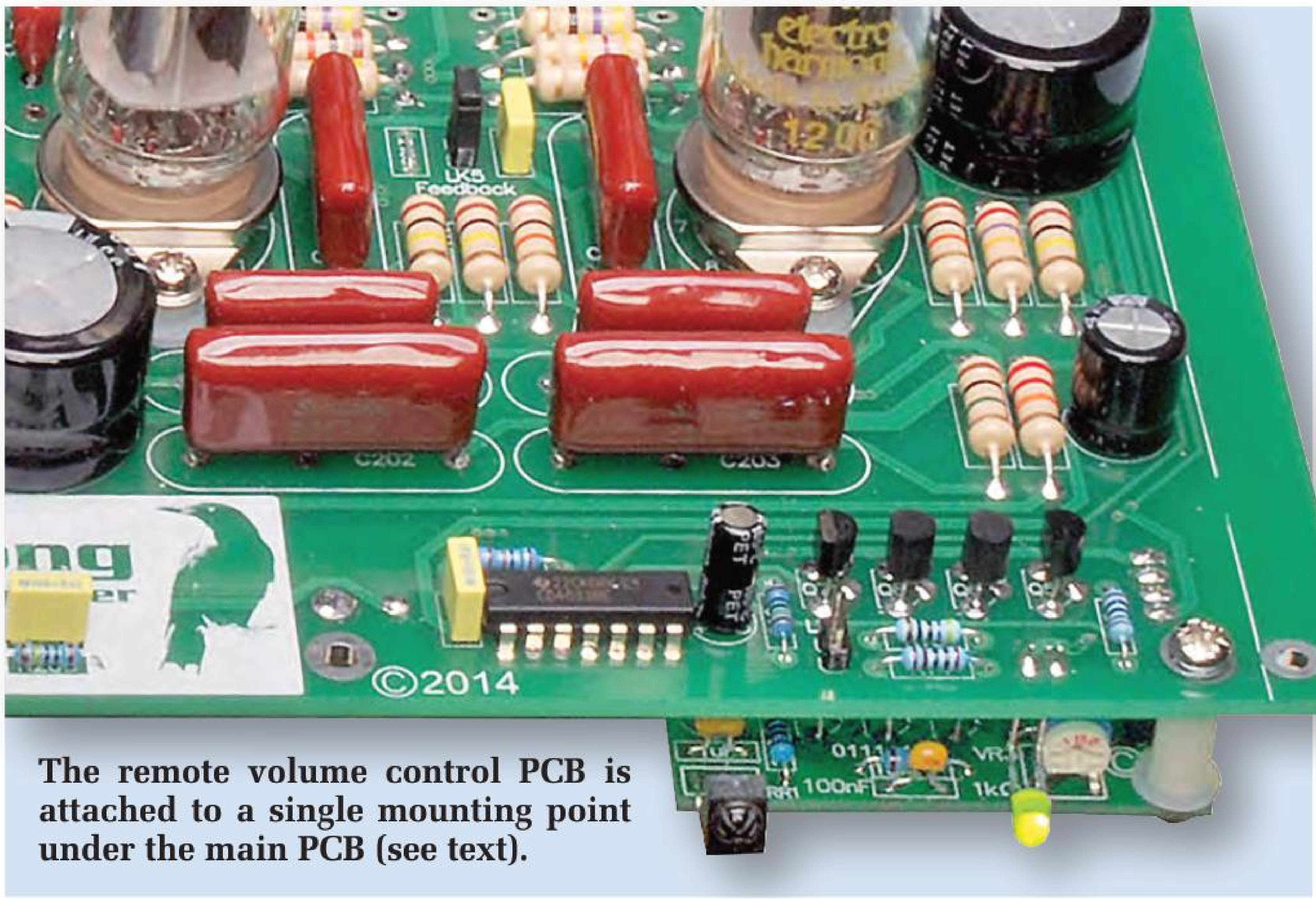
Trimpot VR1 is a vertical type, so that it can be accessed once the remote control board has been plugged into the main board. You will need to bend its rear pin out slightly to fit the mounting pads. The three electrolytic capacitors can then go in, with their longer (positive) leads oriented as shown.

Table 4: Capacitor codes

Value	µF Value	IEC Code	EIA Code
1µF	1µF	1u0	105
100nF	0.1µF	100n	104
22pF	NA	22p	22

Table 3: Resistor colour codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	1	18kΩ	brown grey orange brown	brown grey black red brown
☐	5	10kΩ	brown black orange brown	brown black black red brown
☐	4	1kΩ	brown black red brown	brown black black brown brown
☐	1	100Ω	brown black brown brown	brown black black black brown
☐	1	22Ω	red red black brown	red red black gold brown
☐	1	10Ω	brown black black brown	brown black black gold brown



The remote volume control PCB is attached to a single mounting point under the main PCB (see text).

The infrared receiver is fitted with its leads bent so that the bottom of the receiver is level with the PCB, but it is spaced about 6.5mm away from the bottom of the board – see photo. You will need to bend its leads backwards close to the body of the receiver, then crank them up, then bend them back down again about 8mm behind the body of the receiver to fit through the holes on the PCB.

The final adjustment to make the infrared receiver 'look' through its front panel hole will be done later, when the board is fitted.

You can now finish the remote PCB assembly by plugging microcontroller IC2 into its socket, with pin 1 at left.

Installing the remote PCB

Solder a 4-pin male header to the underside of the main PCB, at bottom-right, to match up with the female header socket (CON11) on the remote board. While you're at it, feed the leads of the remaining 1µF ceramic capacitor through the holes in the two terminals on the back of the pot motor and solder them in place. Trim off any excess lead.

Now you will need to make up the lead for the pot motor. Start by cutting a length of light-duty figure-8 cable so that it will reach from the rear of the pot over to the right-angle pin header on the remote board. Be a little generous, keeping in mind the orientation of the plug and the fact that you will need some slack in order to plug it in.

Strip and separate the wires at both ends of this cable and crimp both wires at one end into two polarised header pins. We like to solder the wires after crimping (being careful not to get any solder outside of the crimp section) so that they can't pull out.

Next, push the pins into the polarised block using a small jeweller's screwdriver. They should click into place. If they won't go in, don't force them; you may need to pull them out and straighten the 'springy' section before they will go in properly.

Now solder the other ends of the lead to the pot motor terminals (or to the capacitor leads which are already soldered to them). Unfortunately, there's no good way to figure out the polarity so you'll just have to pick one and then reverse the connection if it's wrong but we'll get to that later.

Next, insert an M3 × 6mm machine screw through the sole mounting hole on the remote control board, head on the underside, with a shakeproof washer under the screw head. Place a nylon washer on top and then screw it into an M3 × 9mm tapped spacer. Do it up nice and tight.

Plug the remote board into the 4-pin header on the main board, then use another M3 machine screw and a flat washer to hold it in place via the provided mounting hole on the main board. Finally, plug the polarised header from the motorised pot into CON11 on the bottom of the remote board and you are ready to test it.

Note that the pot motor lead should not be able to reach the mains switch which, in any case, should be completely covered in heatshrink tubing.

The next step is to drill a 4mm-diameter hole in the front panel for the IR receiver. **This 4mm hole should be positioned exactly 27mm to the left of the power LED (LED1).** Having done that, leave the front panel off for the moment, so that you can set VR1 correctly and if necessary, swap the motor polarity.

Initial power up and testing

When we left off last month, we had built the PCB and plinth, wired up the power supply and mounted the PCB in place. Now it's time to power it up *without* the valves in place and check that the power supply is working.

Start by popping the fuseholder out of the mains input socket using a flat-bladed screwdriver, then fit the fuse (plus a spare) and re-install it. Leave LK4 and LK5 off the board for now. **From now on until the top cover is fitted, be careful to avoid putting either of your hands near any of the components on the top of the board – touch the assembly using insulated probes only.**

WARNING! HIGH VOLTAGES

High AC and DC voltages are present in this amplifier. In particular, mains voltages (230V AC) are present on the IEC socket and the primary side of the mains transformers (including the wiring to the power switch). In addition, the transformer secondaries together provide a 114V AC output and the power supply produces an HT voltage in excess of 300V DC, which is present on various parts of the amplifier circuit (including the output transformers).

Do not touch any part of the amplifier or power supply circuitry when power is applied – you could get a severe or even fatal electric shock.

The blue LEDs in the circuit indicate when high voltages are present. If they are lit, the power supply and various parts on the amplifier board are potentially dangerous. **The completed amplifier must be fitted with perspex covers – as described in Part 3 this month – to ensure safety.**

Parts list: Currawong Remote Control

- 1 double-sided PCB, available from the *EPE PCB Service,* coded 01111144, 50 × 50mm
- 1 4-pin header, 2.54mm pitch (CON10)
- 1 4-pin female header, 2.54mm pitch (CON11)
- 1 1kΩ mini vertical trimpot (VR1)
- 1 4MHz crystal, HC-49 (low-profile if possible*) (X1)
- 1 3-pin header, 2.54mm pitch, with shorting block (LK7)
- 1 18-pin DIL IC socket
- 1 2-pin right-angle polarised header
- 1 2-pin polarised header plug with crimp pins
- 1 200mm length light-duty figure-8 cable
- 1 9mm tapped nylon spacer
- 3 M3 × 6mm machine screws
- 1 M3 nut
- 1 3mm ID shakeproof washer
- 1 3mm ID flat washer
- 1 3mm ID nylon flat washer
- 1 universal remote control
- 1 PIC16F88-I/P programmed with 0111114A.HEX (IC2)
- 1 infrared receiver (IRD1)
- 1 7805 5V linear regulator (REG2)
- 2 BC327 PNP transistors (Q10,Q12)
- 2 BC337 NPN transistors (Q11,Q13)
- 1 BC547 NPN transistor (Q14)
- 2 1N4148 signal diodes (D7,D8)

- 3 100µF 16V electrolytic
- 2 1µF monolithic multi-layer ceramic
- 3 100nF monolithic multi-layer ceramic
- 2 22pF disc ceramic

- 1 18kΩ
- 5 10kΩ
- 4 1kΩ
- 1 100Ω
- 1 22Ω
- 1 10Ω

* If using a full-height can crystal, add 1 × 20mm length of 10mm-diameter heatshrink tubing

Now set your DMM to DC volts (with a range that goes up to at least 300V), plug in the mains cord, switch on and observe the LEDs. The four blue LEDs adjacent to output transformers T3 and T4 (LEDs3-6) should immediately light. Blue LED2, next to the headphone socket should remain off and LED1 (power) should be red.

If your amplifier doesn't display this behaviour, switch off immediately and wait for the HT voltage to drop to a safe level before troubleshooting. This can be monitored by connecting the negative probe of your DMM to one of the valve socket mounting screws and the positive to the cathode (striped end) of D1. Wait for it to drop below 40V before touching the board and to 10V before doing any soldering or other work on the board.

Assuming blue LEDs3-6 are working properly, these indicate the state of the HT rail. They will be glow brightly when dangerous voltages are present and dim significantly once the HT capacitors have discharged to a safe level. Note that they will continue to produce a small amount of light for a long time after switch-off, but will be quite dim by the time the HT rail drops below 10V or so.

If these LEDs do not light up, one or more could be installed with the wrong polarity or might be faulty. Once the HT has discharged, you can connect a current-limited voltage source across each LED to check them. Some (but not all) multimeters can light blue LEDs when set on diode test mode.

If LEDs3-6 are working but LED1 does not come on, this points to a possible fault in the low-voltage AC wiring, the regulator section or a problem with IC1 or Q5-Q8 and associated components. Check these areas, starting by measuring the voltage between pins 4 and 5 (the two topmost pins) of one of the 9-pin valve sockets, which should be stable at just above 12V and proceed from there.

On the other hand, if LED2 is on, that suggests a fault in Q9 or its base resistor or a short circuit in that section of the board.

Assuming that you get the correct LEDs lighting, LED1 should turn green about 20 seconds after switch-on. During this time, you can check that the various voltage rails are correct.

First, measure the DC voltage between pins 4 and 5 of the 9-pin valve sockets as mentioned above and check that you get close to 12.3V. You can also confirm that there isn't too much ripple on the regulated supply by measuring the AC voltage between these pins; it should be below 100mV.

Now check the unfiltered HT supply voltage, between the cathode of D1 and one of the valve socket mounting screws. You should get a reading close to 320V.

The filtered HT voltage can be measured between pin 3 of any 8-pin valve socket and one of the earthed mounting screws. Pin 3 is the pin closest to you, on the right – see Fig.6 in *Part 2* last month. This should give a low reading (a few volts) initially while LED1 is red and then it should shoot up to 318V or so (ie, a couple of volts below the unfiltered HT rail) as soon as LED1 turns green.

The other filtered HT rails can also be checked, at pins 1 and 6 of each 9-pin valve socket (lower-right and upper-left respectively). With the valves not yet fitted, these should all be pretty close to the main filtered HT rail at around 318V, although they will rise more slowly after LED1 turns green.

Testing the remote board

If you have fitted the remote control board, this is a good time to test it now that you have determined that the power supply is working properly. First, set your remote control to one of the supported codes. For the Altronics A1012, this is either 023 or 089. For the Jaycar AR1719, use 97948 (Philips 02 CJ 412 TV).

Now aim the remote control at the receiver and hold down the volume up or volume down button. You should see the acknowledge LED (LED1) flash and the pot shaft rotate.

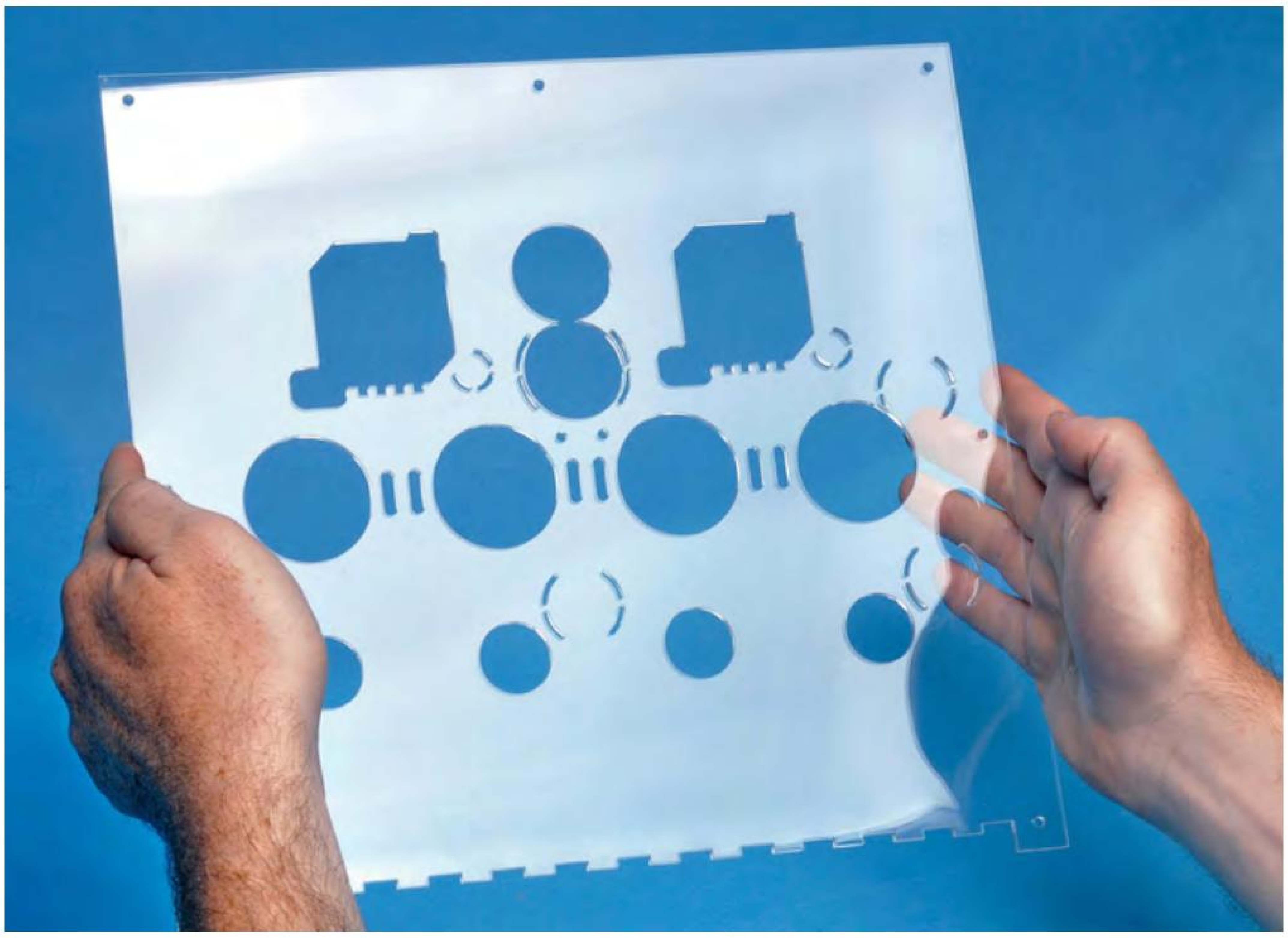
If nothing happens and you have definitely programmed the remote for the correct code then that suggests either a fault on the remote control board or an improperly programmed PIC micro. Check that the board's 4-pin header (CON11) is plugged in correctly to the main board and that there is around 15V between pins 1 and 4.

If the pot rotates in the wrong direction, you will need to switch off and reverse the motor connections (once the HT rail has discharged sufficiently). This can be done by using a fine flat-bladed screwdriver to press in the retention tabs on the polarised header pins, then sliding the pins out of the housing (while holding the tabs down) and refitting them so that they are swapped around.

Once you have the pot motor rotating correctly, press the mute button and check that the pot rotates to the fully anti-clockwise position and stops. If it doesn't stop, turn VR1 clockwise until it does. If it only rotates part of the way, turn VR1 anticlockwise until it mutes properly.

Ideally, VR1 should be set about mid-way between the too-low and too-high positions, to avoid later malfunctions if the pot shaft's mechanical resistance increases slightly.

Note that you may need to manually rotate VR1 clockwise to about half-way (or use the volume up button) before the mute function can be tested. Once it has been set up, you can refit the front panel and if necessary, bend the leads of IRD1 and LEDs1and2 so that they line up with their respective holes.



This is the laser-cut clear acrylic top cover for the main PCB assembly (the white colour is a reflection). Not shown are the front cover and the four pieces that are attached as shield plates to guard the output transformer connections. Acknowledgements: we'd like to thank Ada Lim and the people at Sydney hackerspace 'Robots and Dinosaurs' for their help with the laser cutter.

Fitting the valves

Assuming that the voltages check out, switch off the power and wait for the HT capacitors to discharge, then plug in all the valves. The sockets will probably be very stiff the first time they are fitted; a small amount of contact cleaner on the pins can help ease them in.

Don't push them too hard; you will need to wiggle them in and it's better to push down on the octal valves by holding the base rather than the envelope. The 12AX7s have no base but they should require less insertion force anyway.

The glass envelopes are pretty strong but they can be broken with enough force and there's also the possibility of the glue holding the envelope to the base giving way. So slowly wiggle the valves in. After the first couple of insertions, the sockets will loosen up and fitting/removing the valves will be a lot easier.

This may seem obvious, but we should point out that V5-V8 will get very hot during operation and you should not touch them! Even brief contact can result in a painful burn. Consider that with the glass envelopes and about 25W dissipation, they are similar to an incandescent light bulb – ie, they get very hot!

Now, while we have provided a minimal output load on the PCB (~470Ω per channel), it's still a good idea to hook up a 'proper' dummy load until you're ready to connect some speakers, to prevent flash-over due to excessive voltage when the amplifier is lightly loaded. A couple of 10Ω 5W resistors connected across the speaker terminals will do, although any value in the range of 3.9-100Ω is acceptable.

Turn the volume control right down initially. If you have an oscilloscope and signal generator, you can feed sinewave signals into the inputs, power the unit up, advance the volume control and check the shape of the output waveforms on each channel. Otherwise, all you can really do is hook up a signal source (eg, a CD player) and some speakers and listen to it.

Note that there won't be much output (if any) until several seconds after HT has been applied (ie, LED1 has turned green), as it takes time for the various bias voltages in the circuit to stabilise. And it takes several more seconds until the amplifier can deliver a significant portion of its rated power. The warm-up is complete and the full ~10W/channel is available around 10 minutes after switch-on.

Before that, you'll probably run into clipping at 8-9W per channel. It simply takes that long for the valves to reach operating temperature.

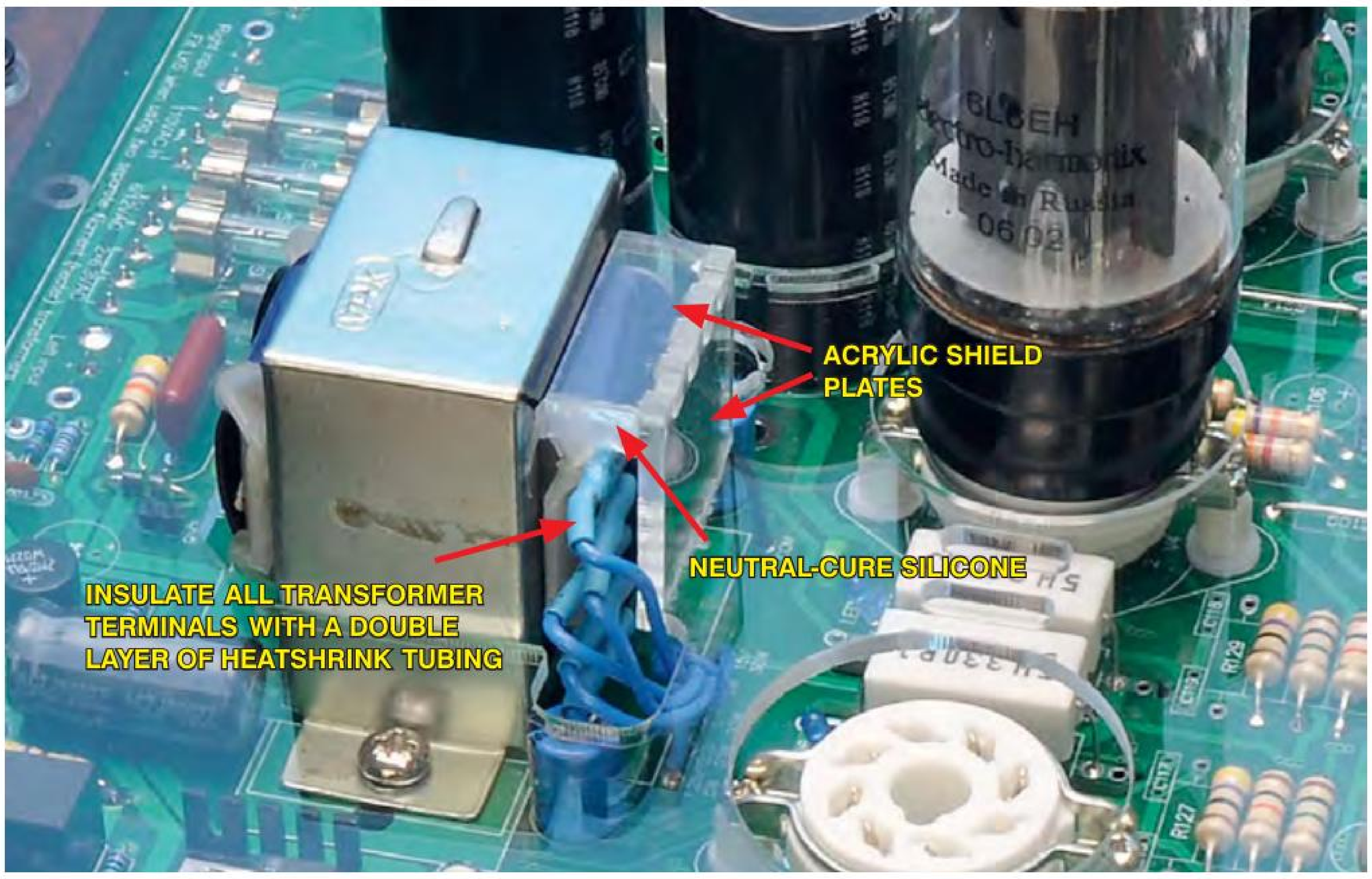
Assuming it appears to be working normally, switch off, turn the volume control back down and fit shorting blocks to LK4 and LK5 to enable global feedback. This dramatically lowers distortion, from around 0.5-1% down to 0.05-0.1% (ie, by at least an order of magnitude) so we definitely recommend operating the amplifier with these links in.

Now switch the amplifier back on, slowly turn the volume back up and check that it's still working properly. If you get a high-pitched squeal, you may have wired the output transformers improperly, turning the negative feedback into positive feedback and causing oscillation. You'll have to switch off and check the transformer wiring and feedback components (resistors/capacitors).

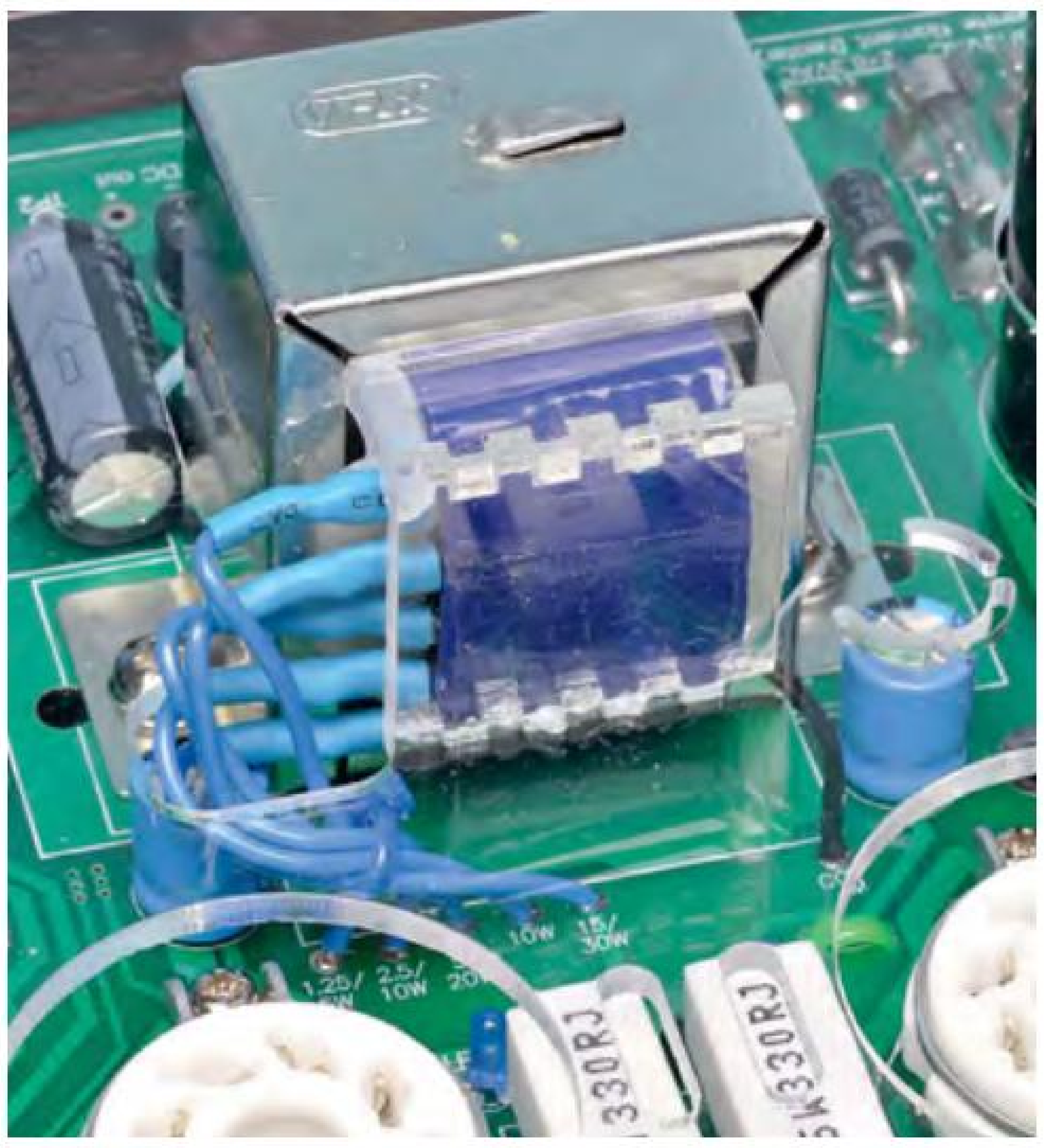
Making the top cover

The top cover is vital since contact with some of the components during operation could be lethal. We've designed a clear acrylic top cover to suit the plinth as described last month, so you can still see all the circuitry while keeping it safe. It also helps to keep dust and dirt off the board (although not entirely, since there are cooling slots cut into it).

Technically, acrylic plastic is polymethyl methacrylate and is sold (with some variations in the formulation)


ACRYLIC SHIELD PLATES
NEUTRAL-CURE SILICONE
INSULATE ALL TRANSFORMER TERMINALS WITH A DOUBLE LAYER OF HEATSHRINK TUBING

The two shield plates for each output transformer are glued together at right angles and then glued at right angles to the main cover. Some neutral-cure silicone is also used to provide further protection and to help hold the acrylic shield plates in place.



Another close-up view of the output transformer shield. Don't leave this shield out – the transformer terminals operate at 308V DC so it's an important safety feature.

under several brand names, including Plexiglas, Perspex and Lucite.

The cover panel may be included in kits – but do check, especially the Altronics kit (K5528) – or you can purchase it direct from: www.siliconchip.com.au/Shop/7/2877. Alternatively, if you have access to a laser cutter with a bed of at least 300 × 300mm, you could cut it yourself. The cutting file is available on the *EPE* website in various formats including DXF, SVG and PDF as a free download.

We used a laser cutter with a 50W CO_2 laser and found that we got good results cutting the 3mm acrylic using two passes at 50% power.

Once you have your cover, check which way around it goes (the cutouts are not symmetrical), then slip it over the top of the assembly to make sure that it fits in place and that the plinth mounting holes are not too far out of their expected positions. Leave the protective film on for the time being. **If you're using valves with large envelopes (eg, KT66s) then you may have to remove them in order to fit the cover.** 6L6s can be left in place. Push it down until it sits on top of the low-profile 39µF capacitors.

If it won't go all the way down, chances are you haven't positioned transformers T3 and T4 in the middle of their mounting locations. It's possible to carefully loosen their mounting screws, just enough to move the transformers, then tighten them again without having to remove the board.

Now remove the cover and peel the protective film off the five pieces to be glued. These all have crenellated edges (like a castle rampart, with a series of square protrusions). **While super glue (cyanoacrylate) is suitable for gluing acrylic, we recommend that you use a proper, solvent-based adhesive, as this will give a much stronger bond.**

We used SciGrip Weld-On 16, fast-setting 'clear, medium-bodied solvent cement'. This states on the label that it's suited for butyrate, polycarbonate, styrene and acrylics. You are unlikely to find this type of adhesive in a hardware store, but should be able to get it from a plastics supplier.

This forms a strong bond quickly so you only have about 30 seconds to mate the pieces and ensure that they are square before it's too stiff to manipulate. Full strength is achieved after about 24 hours. The bond is clear but you don't want to get excess adhesive on the material as it will affect the surface finish and you definitely don't want to drip it on the cover. It tends to get a bit 'stringy' (sort of like melted mozzarella) after coming in contact with the acrylic.

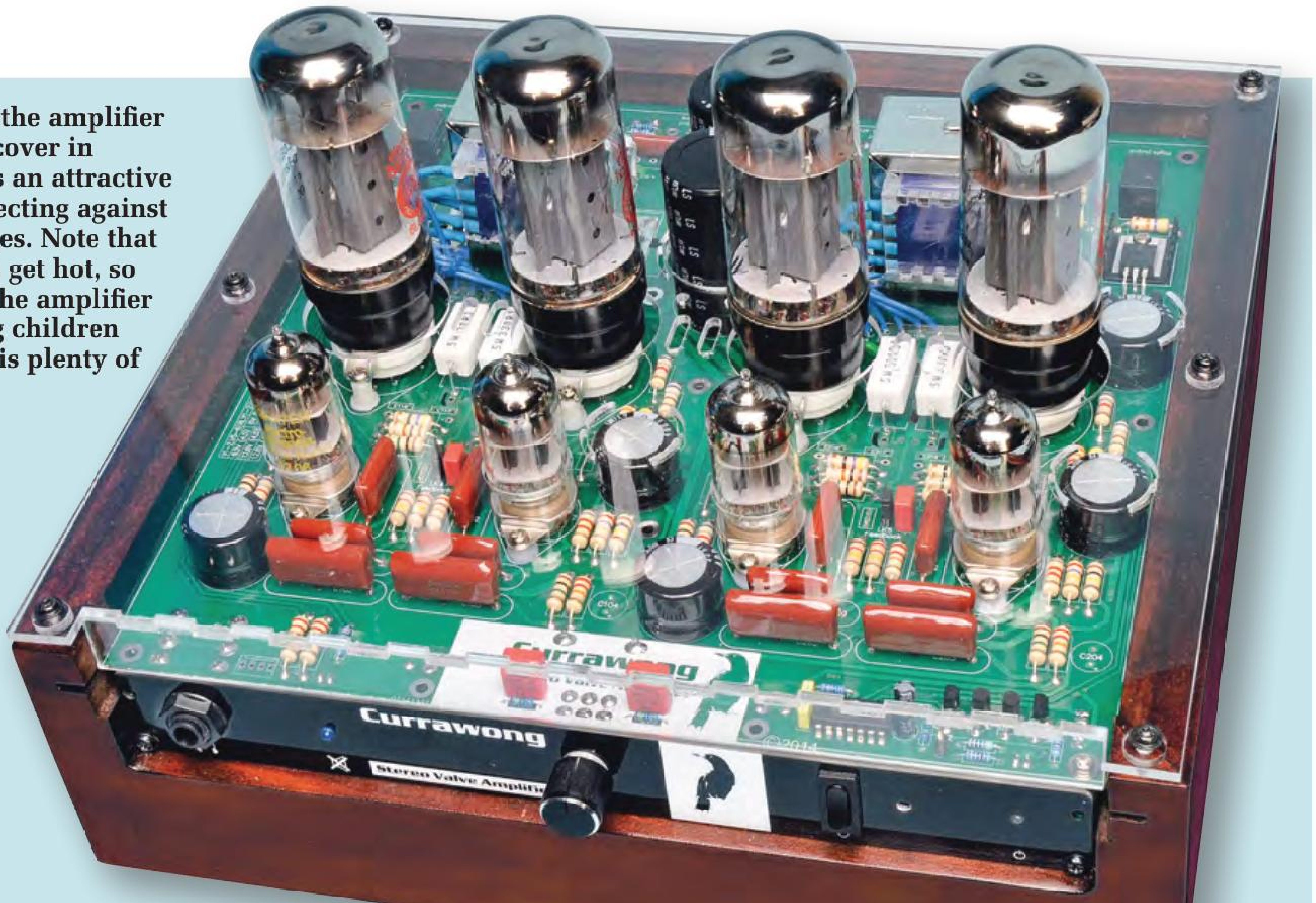
In fact, to give yourself the best chance of getting a clean-looking bond, we'd recommend squeezing some of the adhesive out onto a smooth piece of timber or metal (not plastic!) and using a small paintbrush (hair, not nylon) to apply it to the acrylic. This makes it easier to control how much you are applying compared to using the tube directly. You'll also need a clean rag on hand.

Start by gluing the two pairs of transformer shield plates together. Before applying any adhesive, figure out which surfaces will be in contact (they are on two faces). That done, apply a thin layer of adhesive to all those surfaces, then press the two pieces together. Make sure that they are at a 90° angle and that the tabs are fully inserted into the slots. Wipe off any excess adhesive and be careful not to get it on areas of the acrylic away from the join.

You can then lay the part on its side to cure. Do the same for the other identical piece. Note that while there are two different orientations in which these pieces can be glued together, it doesn't matter which way you do it as they are symmetrical.

Once you've done those, you can move onto gluing the front and top sections together. This is a much larger join but the technique is basically the same. **However, the orientation does matter in this case – be sure to glue the front section on such that when the cover is in place, it hangs down rather than sticks up.** Acrylic adhesive is very strong, so if you get it wrong, you probably won't be to get them apart again without breaking something.

Again, it's important to make sure that the sections are at right angles and pushed fully together to get a neat result. You will need to peel away the protective film from the top cover near the front but it's a good idea to leave it in place on the rest of the panel



This view shows the amplifier with the acrylic cover in place. It provides an attractive finish while protecting against dangerous voltages. Note that the output valves get hot, so be sure to place the amplifier away from young children and where there is plenty of ventilation.

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Before switching on

- **Check that the IEC socket's earth pin is connected to all exposed metalwork.**
- **Check the isolation between the live and earth pins and neutral and earth pins of the IEC socket.**
- **Check the output transformer and mains switch insulation. The output transformer terminals must be fully insulated with a double layer of heatshrink.**
- **Don't touch any parts if the unit is being tested without the cover.**
- **Be sure to fit the cover when testing is complete.**

to protect it during gluing. The best way to do this is to peel back the film around the area to be joined and then use a pair of scissors to cut a strip of it away, so the rest can be laid back down on the surface.

Once you've joined those parts, leave it for a few minutes and it should then be strong enough to allow you to glue the two transformer cover pieces prepared earlier into the crenellated sections at the front of the transformer cut-outs. Glue the pieces in so that the horizontal pieces at the top project out over the cut-out areas in the top cover below (ie, not pointing towards the front of the panel).

Fitting the top cover

While full strength won't be achieved for 24 hours, the joins should be strong enough after about 10 minutes to allow you to (carefully) fit the cover to the amplifier. Again, if using KT66s or other valves with envelopes larger than the 6L6s, remove them first.

Lower the cover until it's resting on top of the five low-profile capacitors. Take care to avoid touching the underside as this may leave visible fingerprints. If you do get fingerprints, polish them off with a soft cloth.

You may need to push down on it gently but firmly to get it to go all the way down. If it won't go, re-check the positioning of T3 and T4 and move them slightly if necessary.

You can then mark out the seven mounting hole positions around the perimeter of the cover and drill 2mm pilot holes a few millimetres deep in each location. You can remove the cover to do this if you want to (which makes it easier to remove the resulting wood particles) – however, it isn't strictly necessary.

Next, peel the protective film off seven of the small doughnut-shaped laser-cut pieces. Once you've cleared the area around each hole, slip these 'doughnut' spacers under the cover and push them into place (eg, using a screwdriver). You can then feed a 4G × 12mm self-tapping screw in from the top and do it up until the top panel is resting on the spacer. You may want to do up all seven screws loosely and then slightly adjust the top cover position before making them all tight to hold it in place.

All that's left now is to squeeze a small bead of neutral-cure silicone sealant into the gap at the upper-left corner of each output transformer. This helps hold the acrylic covers in place and also prevents small fingers or other objects from being pushed into this gap (see photo). The easiest way to do this is to cut a thin strip of plastic from a take-away container lid or similar, place a bead of silicone on the end and use it like a trowel to push it into the gap and wipe off any excess.

Once it has all dried you can plug the valves back into their sockets and the amplifier is ready to go! **Note that the output valves get hot in operation so be sure to place the amplifier where there is plenty of ventilation.**

Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Dealing with static-sensitive components

WHEN I first became interested in electronics, some electronic projects were based on valves, or 'tubes' as they are called in the US. Protecting components from high voltages was not an issue, since many of them required a few hundred volts in order to work properly! Back then, semiconductors could certainly be damaged by relatively low voltages, but they were not considered to be at risk from static charges in the environment. They were mostly made from germanium rather than silicon, and overheating when soldering them into the circuit was the main problem.

Things are certainly very different these days, and modern semiconductors are far more tolerant of high temperatures. It is still possible to damage semiconductors with excessive heat when soldering them to a circuit board, but the widespread use of semiconductor holders has made this largely academic. The holder is soldered in place on the circuit board, and the semiconductor is simply plugged into the holder.

In charge

Although static electricity was originally not considered too hazardous to semiconductors, it is very much to the fore these days, and probably represents the main source of problems with modern components. If you buy any semiconductor, regardless of its type, it will almost certainly be supplied in some form of anti-static packaging. There is probably a degree of overkill here, with components that were once considered to be free from risk being treated in the same way as the most vulnerable components. So why are some semiconductors more at risk from static charges than others?

Problems with components being zapped by static charges first became a major problem with the introduction of various devices that used MOS (metal-oxide semiconductor) technology. These are based on the MOS version of field-effect transistors, or MOSFETs as they are usually called. Bipolar transistors have low input impedances at the base terminal, and in use, a small but significant current flows at the input of the device. The voltage at the base of a transistor varies very little in normal use, and it is the current flow that is of greater significance.

The gate terminal is the MOSFET equivalent to the base terminal of a 'conventional' bipolar transistor. The input impedance of a MOSFET is extremely high, and only a minute input current flows. In fact, the input current is so low that it cannot be measured using an ordinary test meter. The input impedance is usually a few million megohms. In normal, use the input voltage to the gate of a MOSFET varies much more than the input voltage at the base of a bipolar transistor. However, with the exception of some high power devices, the input voltage is still no more than a few volts.

Semiconductors are often tolerant of high currents for brief periods, but they tend to be easily damaged by even the most transient high voltages. Static charges in the environment are not normally a problem with conventional transistors, because they are quenched by the flow of current into the component. Charges are leaked away through the device without ever building up to anything significant.

However, due to their incredibly high input impedances, MOSFETs do not have this form of inbuilt protection. Static charges can build up between the gate and the other terminals, possibly reaching a high enough level to damage the component. It is important to bear in mind that the actual voltage need to zap a MOS device does not necessarily need to be particularly high. In some cases a potential of around 50V is sufficient to damage a component. There is no need to have a static charge of a few hundred volts or more, complete with crackling sounds and sparks flying. A MOS device can be zapped with no obvious sign of anything amiss. It will simply fail to work for no apparent reason.

Minority group

Any semiconductor device can be damaged by very large static charges, and it is presumably for this reason that even the hardiest of semiconductors are often supplied in some form of anti-static packing. Alternatively, it might just be a matter of economics, with it being more cost-effective to use the same packing for all semiconductors, regardless of whether they need protection from static charges. Anyway, unless a device is definitely known *not* to be a MOS type, if it is supplied in anti-static packing then it should be regarded as a vulnerable component and be treated accordingly.

Although MOS devices were very much in a minority for some years after their introduction, it is probably fair to say that the majority of semiconductors used in modern electronics fall into this category. MOS technology is not so extensive for discrete transistors and diodes. Conventional transistors and MOSFETs have different circuit symbols, so you should always know which type you are using. There is another type of discrete field-effect transistor in the form of the junction gate type, which are often called the 'JFET' (or occasionally 'JUGFET'). While these have high input impedances that are typically in the realms of a few hundred megohms, they are generally deemed slightly less at risk than MOSFETs.

MOS technology has gradually found its way into linear integrated circuits such as audio amplifiers and operational amplifiers. Although at one time linear devices could be regarded as safe from static charges, this is no longer the case, and many operational amplifiers have MOS input stages. Logic integrated circuits used to be divided into the 'safe' 74 series TTL devices, and the vulnerable 4000 series CMOS (complementary MOS) types. However, various improved families of TTL devices have been introduced over the years, most of which are actually based on CMOS technology. Apart from the original devices and the 74LS (low-power Schottky) components, it is best to regard all 74 series devices as vulnerable to static charges.

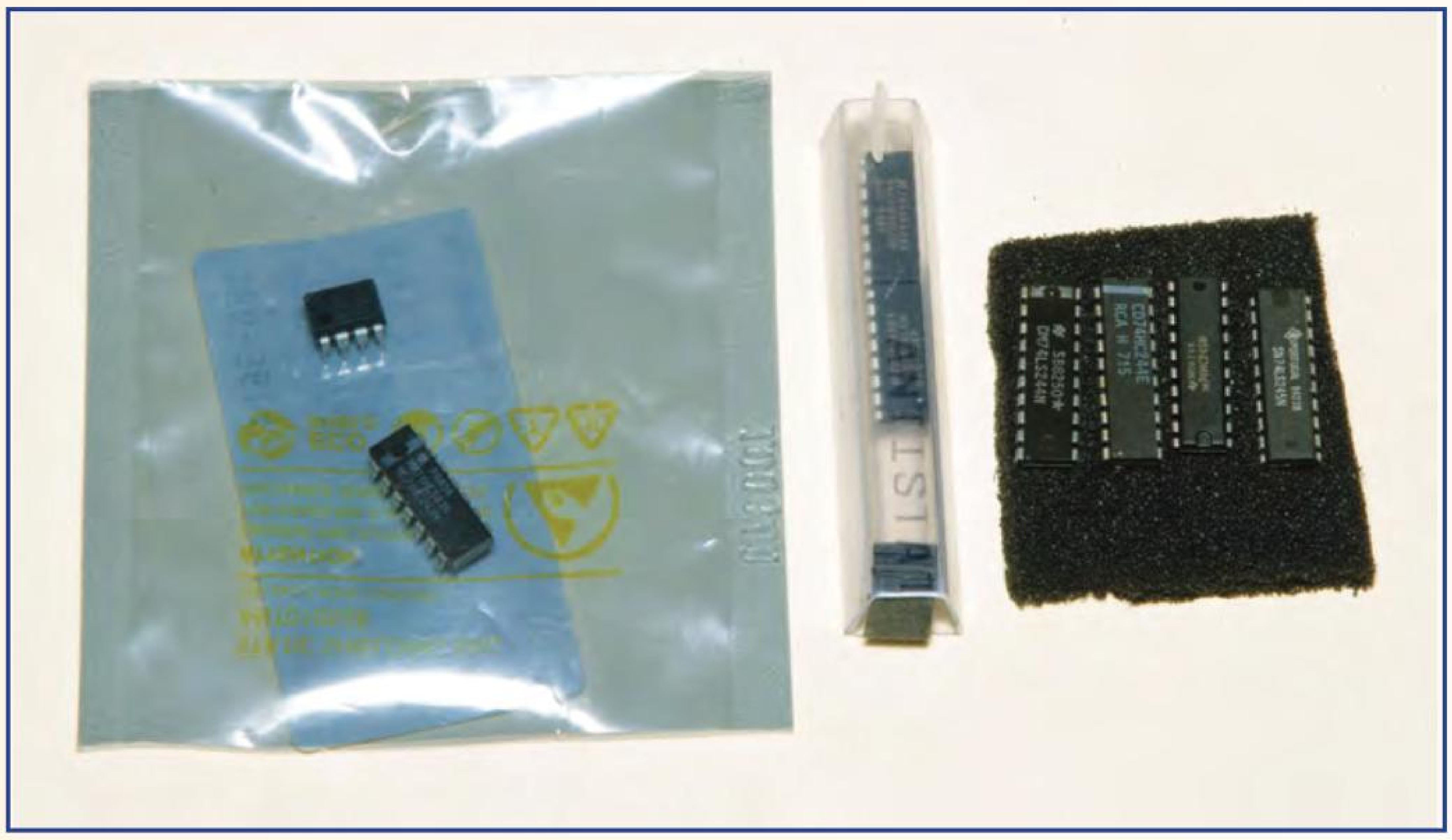


Fig.1. Three types of anti-static packaging. The bag and the tube insulate the devices within from static charges, whereas the conductive foam effectively short-circuits all the pins together so that no significant voltage can exist between them

These days, practically all digital chips are MOS based, including microprocessors, microcontrollers, and their support chips, memory devices, and specialist devices such as digital clocks and signal processors. Even things such as sensors can be based on MOS technology, or include MOS components. When a project uses components that are vulnerable to static charges, they should be clearly identified as such in the article. Component catalogues often indicate the devices that can be easily damaged by static charges, and this information should always be clearly shown in data sheets. The data sheet for virtually any semiconductor component can be found on the Internet by entering the type number and 'data sheet' into a search engine. If in any doubt, always take a 'better safe than sorry' approach, and proceed on the basis that a device is vulnerable to static charges.

Sent packing

MOS devices are supplied in some form of anti-static packing, and they should be invulnerable to static charges while they are in this packaging. Anti-static packing comes in various forms, such as conductive foam, blister packs, plastic tubes, and conductive plastic bags. Some common examples of anti-static packing are shown in Fig.1. There are two basic approaches to preventing damage by static charges.

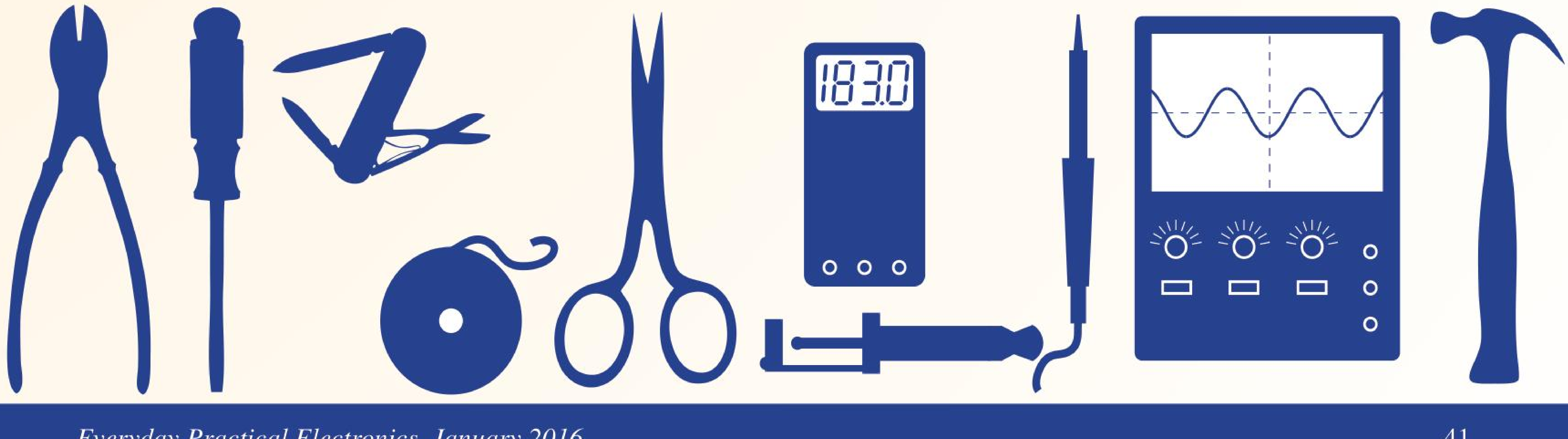
One method provides protection by short-circuiting all the pins or leads of the components together. Strictly speaking this does not actually keep high voltages at bay, but this method works because it is not a high voltage *per se* that causes the damage. Damage occurs when there is a high voltage between two pins or leads of a component, resulting in some of the semiconductor junctions being 'blown'. No significant voltage differences can be produced between pins or leads if they are electrically connected. Conductive foam uses this method to protect devices. The alternative approach is to insulate components from static charges. Blister packs often use a combination of the two methods, with metal foil on the cardboard back connecting the pins, and the plastic blister providing insulation from the outside world.

Careful handling

An initial precaution is to leave devices in their anti-static packaging until it is time to install them on the circuit board. It is tempting to remove the components from their packing to examine them, but this is something that should definitely be avoided. With most types of protective packing you can see the components inside well enough to determine whether the right parts have been supplied. The packaging sometimes has warning notices which suggest that the components will be zapped unless they are dealt with using expensive anti-static equipment. Fortunately, this is not really the case, and some simple precautions and inexpensive equipment will suffice.

An obvious precaution is to keep components well away from any know or likely sources of static charges. You will presumably be all too aware of any large sources of static charges in your home. Keep semiconductors well away from them, and do not build electronic projects anywhere near them. At one time, clothing was often a common source of static charges. However, these days, manmade fibres are normally mixed with natural fibres, and this has largely eliminated the problem. Of course, if you have any clothes that show any tendency to produce static electricity, do not wear them when dealing with semiconductors.

Another obvious precaution is to handle vulnerable components as little as possible when it is time to fit them onto the circuit board. Try to hold components via their bodies,



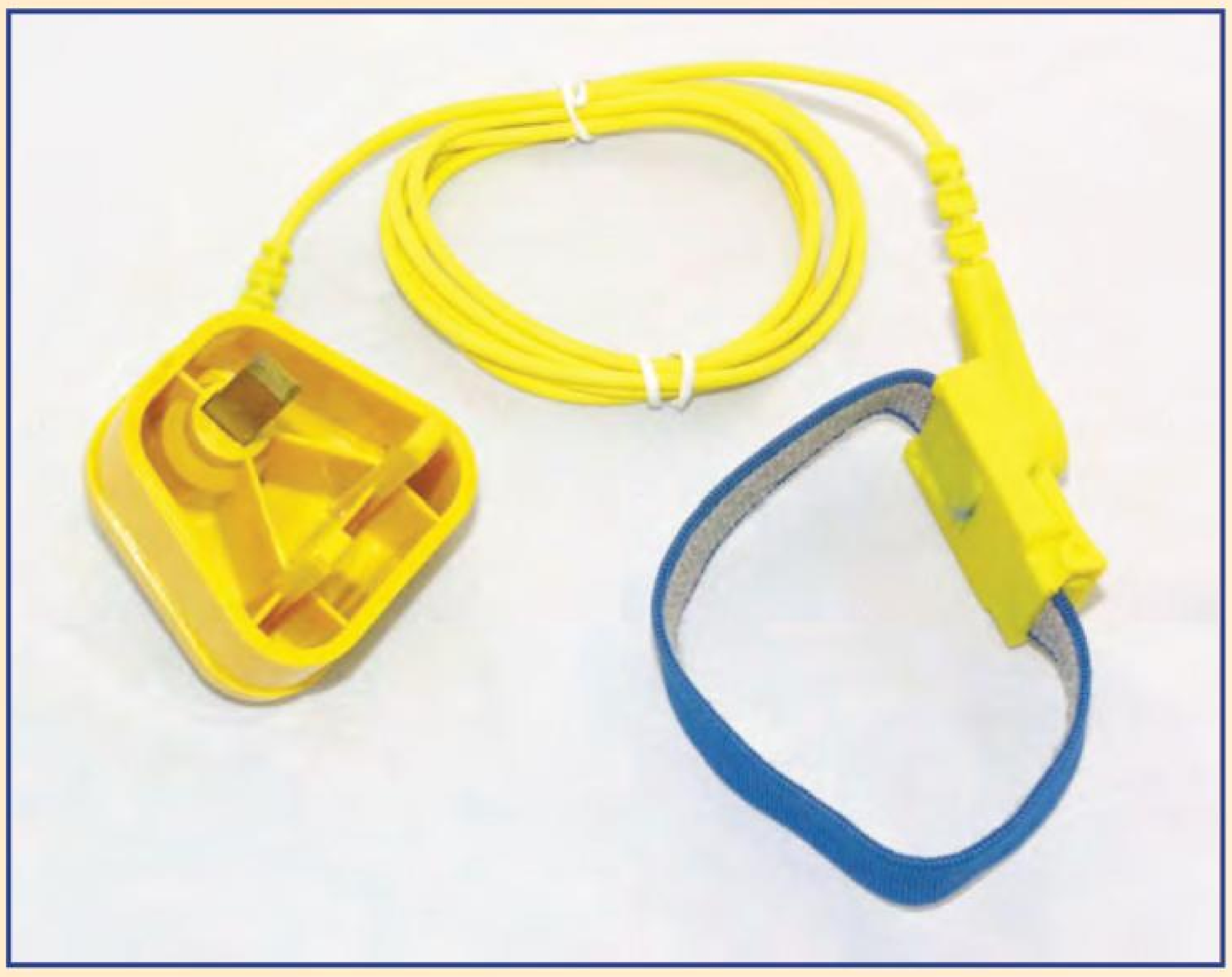


Fig.2. An anti-static wristband, complete with its lead and mains earth plug. For safety reasons there is a resistance of several megohms between the wristband and the plug

and avoid touching the pins or leadout wires any more than is really necessary. Use holders for all integrated circuits, and not just MOS types. In addition to reducing the risk from static charges, using a holder avoids the possibility of overheating components when soldering them to the circuit board. It also makes it easy to correct matters if a component is accidentally fitted the wrong way around. Removing a device from a holder and reinstalling it correctly is quite straightforward. Even if you have the right tools, desoldering multi-pin components from a circuit board can easily result in damage to the components and (or) the board. Integrated circuits should not be plugged into their holders until the circuit board and any wiring has been completed.

Down to earth

These simple procedures will suffice when dealing with inexpensive chips such as most CMOS logic types, but further measures are worthwhile when dealing with more expensive devices. There is certainly no shortage of equipment that can help to keep static charges at bay, and prevent expensive chips from being zapped. While most of this equipment is highly desirable, much of it is not particularly cheap. For professional users who will use it on a daily basis, no doubt this equipment represents good value for money. Unfortunately, it is not a realistic option for most amateur users. The equipment would probably cost more than the total value of the components it would be used to protect.

On the other hand, there are some relatively inexpensive items of anti-static equipment that are well worth having, even if they will only receive occasional use. An earthing wristband is probably the most popular and most-cost-effective item of anti-static equipment. This is comprised of the wristband itself, a mains plug that provides *ONLY* an earth connection, and a lead to connect the two (Fig.2). The lead is sometimes terminated in a crocodile clip rather than the mains plug (Fig.3). The crocodile clip is connected to the earthed chassis of a piece of electronic equipment. Either way, the equipment connects the user to the mains earth so that static charges leak away to earth instead of building up in their body.

Equipment of this type is potentially very dangerous. If the earth lead should become 'live' it would probably be impossible for the user to remove the wristband, and the lead therefore includes a high value series resistor. This ensures that that the current flow would be far too low to cause any injury if anything should go seriously wrong. The resistor does not prevent any static charges from rapidly leaking to earth. A simple alternative to using a wristband is to periodically touch something that is earthed. This could perhaps be the 0V output of a bench power supply unit. This is a less reliable way of doing things, but it should remove any charge from your body well before dangerous voltages can build up.

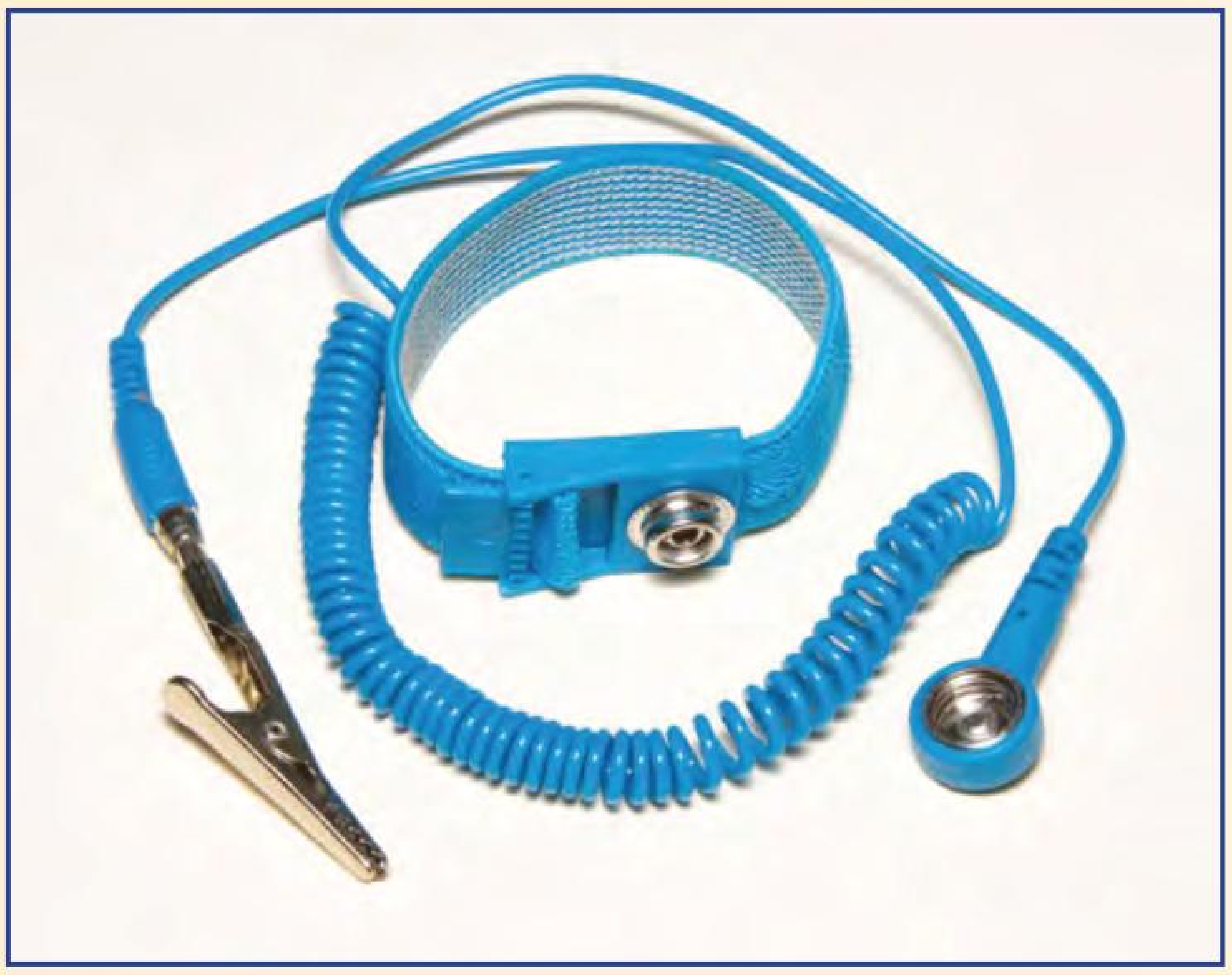


Fig.3. This anti-static wristband has a crocodile clip lead rather than a mains earth plug. It is primarily intended for use when building and servicing PCs, but it is usable when building electronic projects

Mat finish

An earthing mat is another useful item of equipment that can be obtained relatively cheaply (Fig.4). It is a mat made from a conductive material, or from plastic that has a conductive coating on one side. It is used on the workbench, and it is earthed in the same way as an anti-static wristband. The circuit board and any components or tools placed on the mat are earthed, and free from static charges. In fact, the presence of an earthed mat more or less guarantees that there can be no build-up of static charges in the user's body, or anything within the vicinity of the mat.

It is not difficult to improvise an anti-static earthing mat, and something like a piece of aluminium foil glued to a piece of plywood, or some aluminium sheet should do the job well enough. A homemade mat can be earthed via a plug and lead of the type sold for use with anti-static wristbands. However, it is possible to buy anti-static mats for a few pounds each, so the DIY approach is less worthwhile than was once the case.

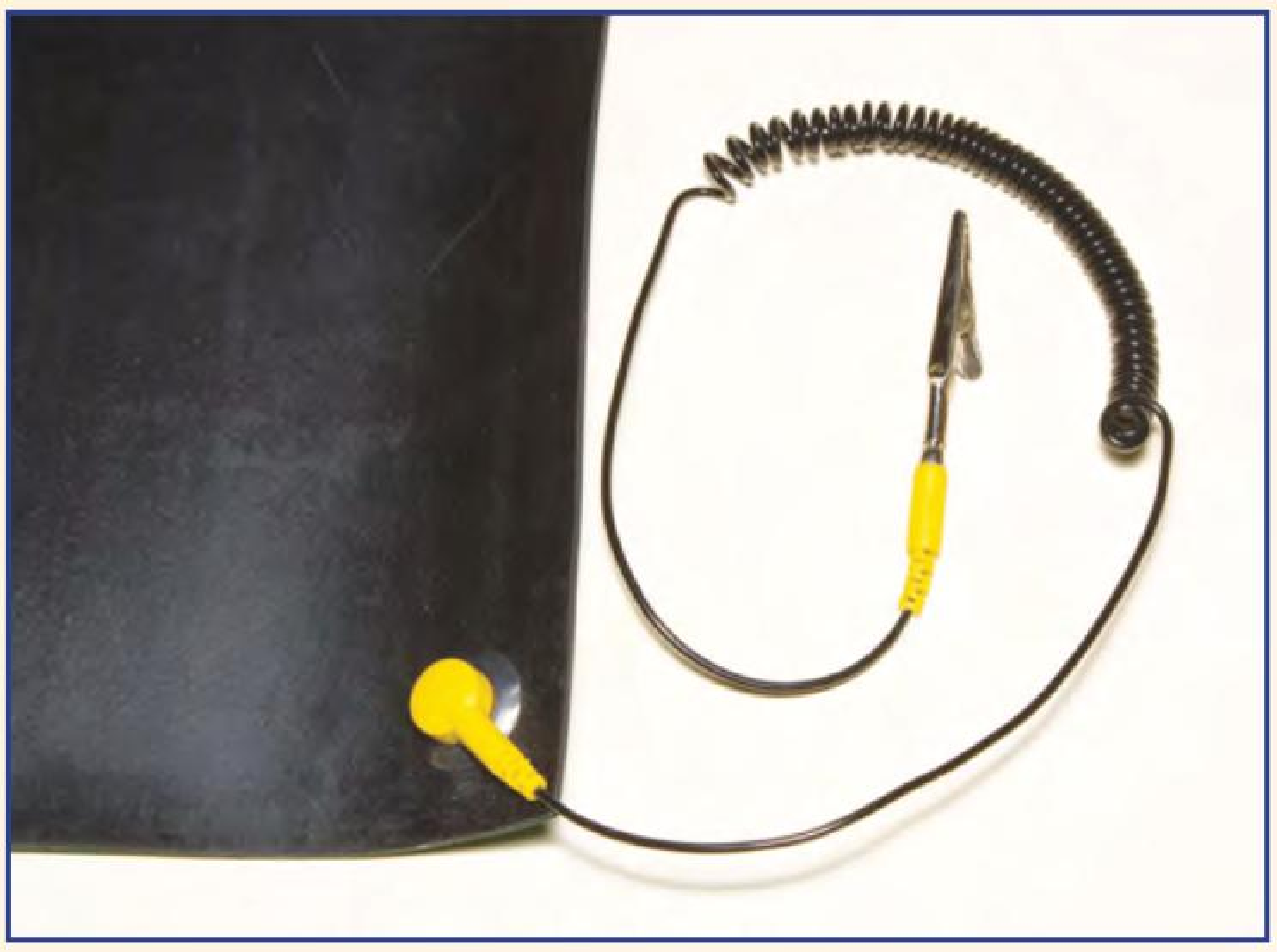


Fig.4. Part of a large anti-static work mat, complete with the earthing lead and clip. It rolls up for easy storage, but is less than completely flat in use.

NET WORK

by Alan Winstanley

Getting the picture

MORE trials with the Ucam 247 HD1080p Wireless IP camera (featured in *Net Work*, December 2015) revealed that the number of files stored on the NAS hovered at exactly 10,000. After changing Guest permissions on the Synology NAS, the camera was no longer storing countless (42,000+) images that needed to be trimmed manually using (for example) the AutoDelete program I mentioned last month. It was speculated that the 10K limit related just to the camera's internal SD card storage, but in fact it was now behaving as I originally anticipated – limiting the archive to 10,000 photos on the NAS instead of building up an endless heap of them.

Objects like passing cars, trees swaying in the wind or birds could generate unwanted snapshots which could quickly hit the 10,000 image ceiling, allowing maybe a few days' worth of files to be stored at most. Some experimentation might be needed to get the balance right:

- Juggling the capture of multiple images against their resolution (hi-res image files take longer to travel, and a slow network might miss some snapshots)
- Network speed (faster rates allow more images to be captured in the allotted time)
- Motion detection coverage (too broad, and too many false triggers might result).

Despite trying all sorts of different permissions and user setups, I could not overcome this 10,000 limit. It would be ideal if captured images could be protected by the stand-alone NAS, without Windows running on a PC to manage the job. Could they be backed up automatically somehow?

The Synology NAS offers just a few compatible apps to backup files onto cloud storage, including HiDrive. The attractive, paid-for cloud service from the German ISP Strato was first examined in *Net Work*, March 2012. Packages start at under £7 a month for 100GB of storage. I like the fact that it can be configured to appear as a 'normal' Windows drive, and both public and private folders can be set up online. HiDrive is also Mac and Linux compatible and has apps for Android, iPad and Windows Phone users. Even without a Synology NAS, HiDrive is a cloud service that techie users will probably appreciate. A free 5GB HiDrive service is also offered (not compatible with the Synology app), and overall it's an interesting package that is independent of big names like Google and Microsoft. At the time of writing, archiving IP camera images this way has not yet been tested by the author, but no problems are expected.

The Ucam 247 is also compatible with 'Cammy', a paid-for subscription service for hosting IP camera images and alerting owners of any 'hits'. This is probably the most hassle-free option for many Ucam users and is worth trialling, mindful of the running costs.

Android on the big screen

A compatible web browser with Quicktime is needed to view this camera's live video on a desktop, but it can also stream lower-resolution video via an app on a smartphone or tablet. The Ucam 247Live Android app works well over Wi-Fi, and the camera's microphone is extremely sensitive. Using a mobile app or my desktop web browser meant I could finally keep an eye on the front of the building. Then I hit upon the idea of viewing the video stream on a Smart TV as well!

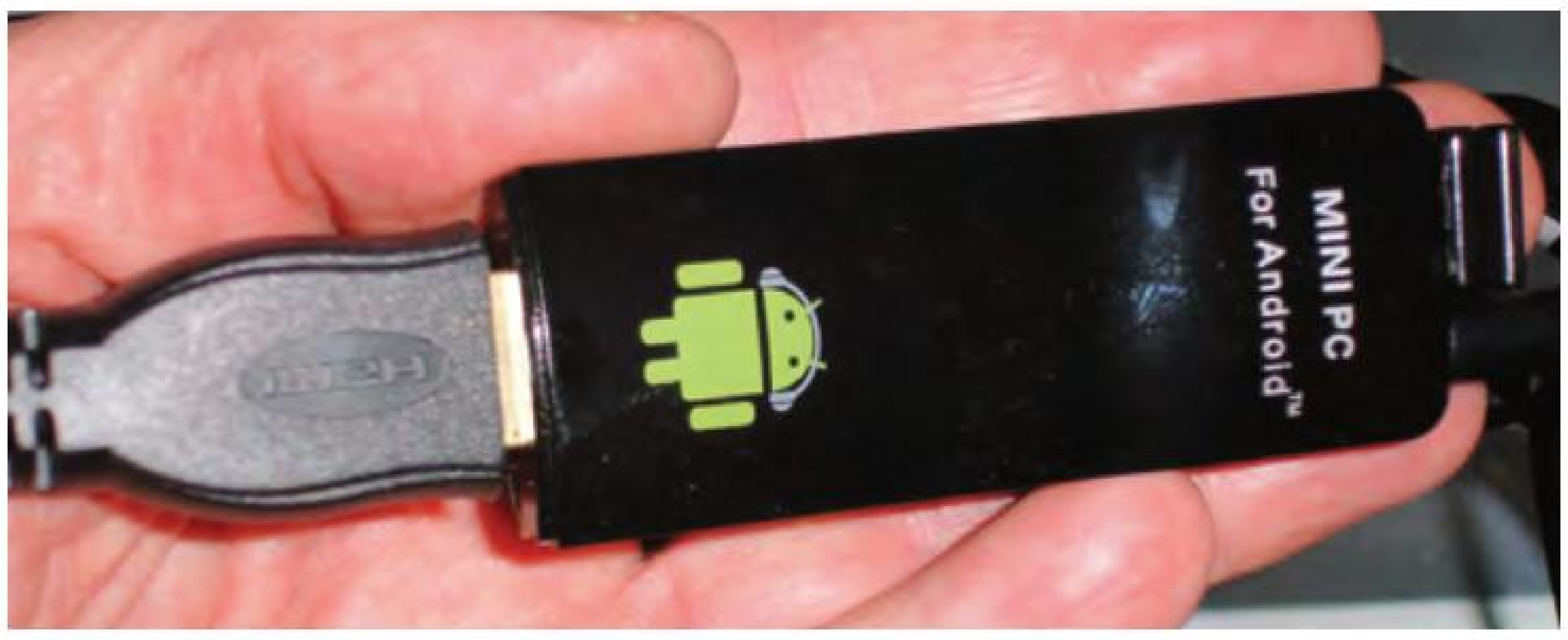


Fig.1. This £20 Android Mini PC dongle turns an HDMI TV into a fully-fledged Android computer with Wi-Fi, Bluetooth and USB

In my case, the Samsung TV's web browser was incompatible, so the camera image could not be accessed via its IP address. Undeterred, I noted my TV had a spare HDMI input, so I decided to try converting it into a fully-fledged Android computer capable (I hoped) of running the Ucam Android app. eBay turned up a likely-looking Android 'Mini PC' HDMI TV dongle from China for well under £20 ($30) – see Fig.1. Measuring just 90 × 30 × 20mm, the diminutive dongle runs Android 4.2.2 and – hard to believe – has about 1GB of RAM, 802.11n Wi-Fi and Bluetooth, USB ports and a MicroSD slot (32GB max.). It has native support for common audio and video files, and a handy HDMI extension lead (included) enabled connection to an HDMI port buried behind the TV. The cheap 5V mains adaptor (US two prong) was replaced with a higher quality one.

So, was a cheap and cheerful HDMI TV dongle like this too good to be true? After powering up, it soon booted into an Android home screen. (Think of older-generation Android tablets from two to three years ago, but still perfectly acceptable today.) Next, I found that it would not pair with a cheap Bluetooth keyboard and trackpad. Bluetooth version compatibility has long been an issue with mobile phones, sat navs and laptops, so instead I tried a legacy £1 Bluetooth dongle on the Android USB port and miraculously the Android screen responded to my inputs.

The Android-powered TV found a nearby Devolo wireless access point and soon I was downloading apps, browsing the web, checking Gmail and Google Calendar, all on the 40-inch TV screen. The Ucam Android app was downloaded and I briefly hit a problem: a cryptic message stated that Ucam 247 'cannot run as Google Play Services is not supported by the [Android] device', even though I knew Google Play was installed and working properly. My heart sank, but then everything suddenly burst into life – the Ucam247 Live app added the IP camera (Fig.2) and I could now see the camera video clearly on full-screen TV, along with sound.

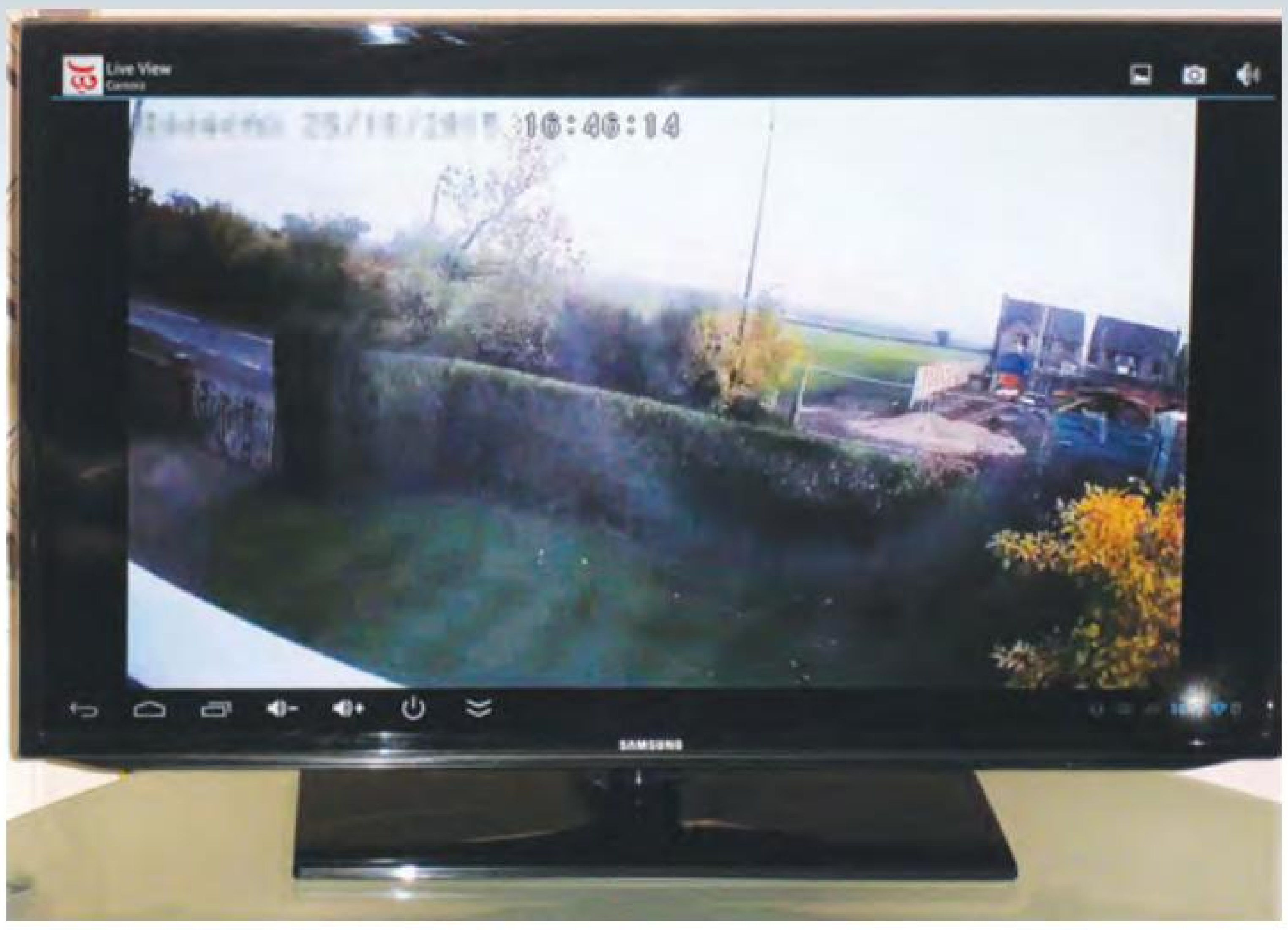


Fig.2. Viewing the Ucam IP camera video with the Ucam Android app on a 40-inch TV

Separately, I installed Firefox and Chrome web browsers for Android and happily, I could now log into the camera's IP address and view the camera online that way, although not at full screen (Fig.3 and Fig.4). (In Chrome, I had to 'Request the Desktop Site' before it would work.) I could also log in and check the camera settings if I wanted to.

Checking around, I must admit the Android HDMI TV dongle exceeded all expectations and worked extremely well; it found various network drives and its media player was soon blasting out MP3 music and MPEG videos hosted on my NAS. Not all Play Store apps worked with this version of Android, but even so, adding an Android TV dongle like this is a very cute way of getting more from an HDMI TV screen or monitor, or adding some useful Google apps, even if only to surf or check mail. For such a trivial cost it's definitely a cheap way of upgrading an HDMI screen. Shop around for a cheap Bluetooth keyboard and be prepared to experiment a little – it's worth it!

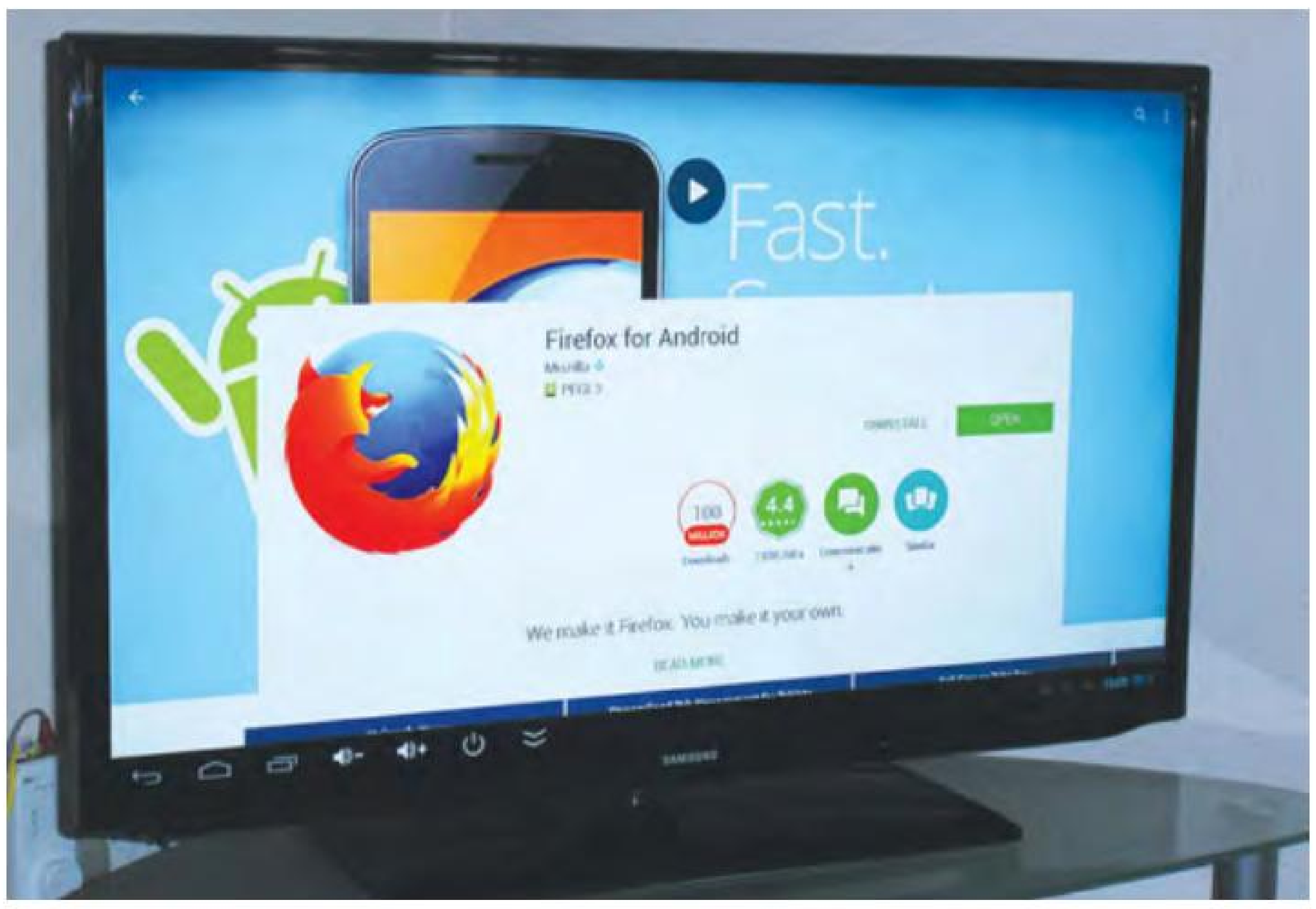


Fig.3. Downloading the Firefox web browser onto the Android dongle using Google Play Store

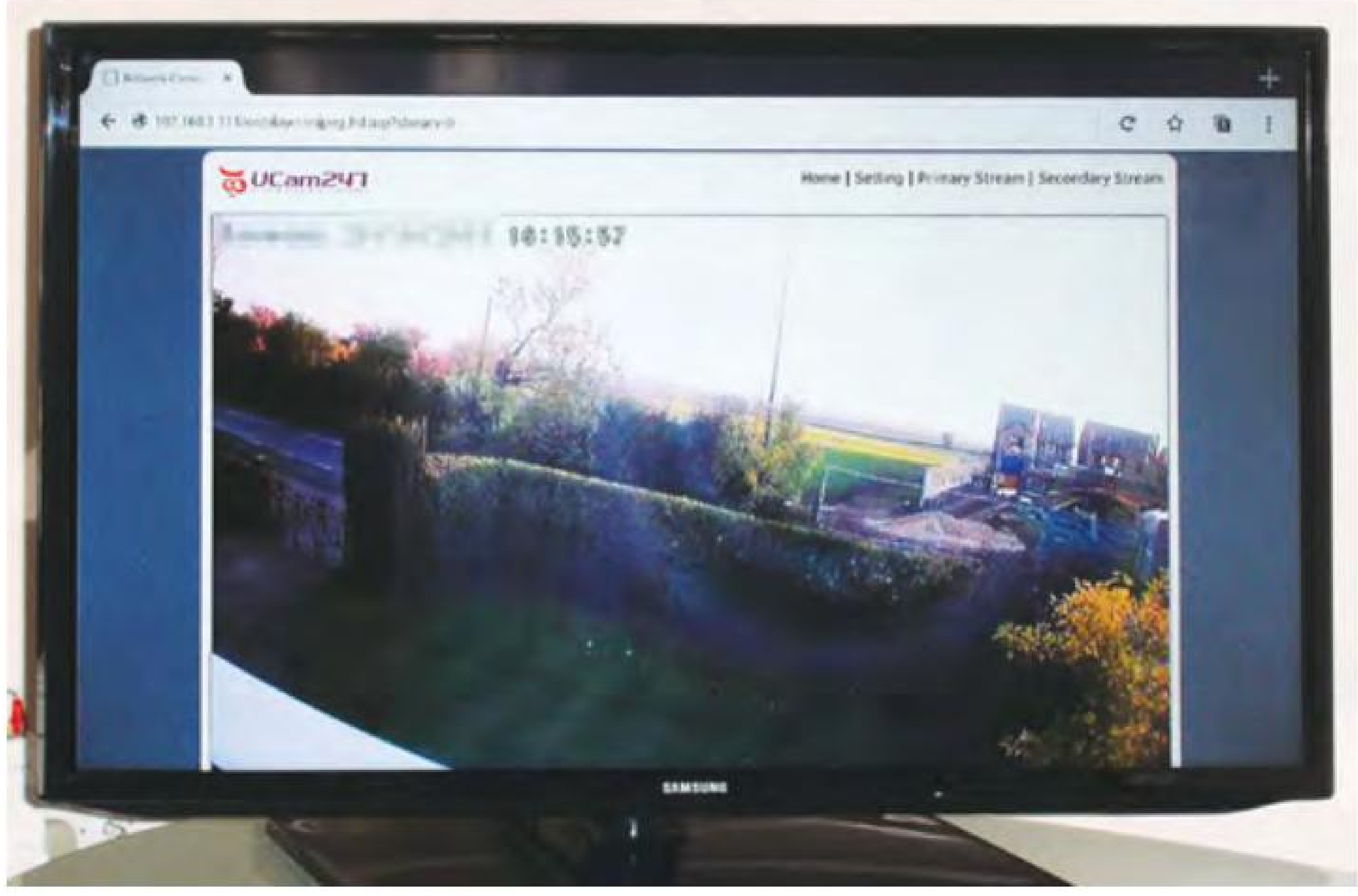


Fig.4. The IP camera video feed and setup screens could then be accessed using its IP address in the browser

intel
inside

Fig.5. Intel Compute Stick is a fan-cooled Windows 8/10 HDMI TV and monitor dongle

Windows users might like the Intel Compute Stick, which offers Windows 8.1 / W10 or Ubuntu 14.04 LTS on a fan-cooled (!) HDMI dongle with Wi-Fi, Bluetooth and USB – but at £80 ($120) it's four times more expensive than the Android device tested here – see Fig.5.

POP music

Readers would expect an Internet columnist to rave about life on the cloud, but I manage my very busy email the same as ever – offline, using good old (and free) Eudora, a program that still offers lightning-fast mail search, multi-threaded mail collection (perfect for my dozen POP3 email boxes) and powerful filtering options. File attachments and mailboxes are stored safely on a local disk and backed up to a NAS using the fast and dependable program Macrium Reflect every night.

The last iteration of Eudora V7.1 for Windows is still downloadable from **www.eudorafaqs.com** and a Eudora mail list server is busy with users' chatter. Apart from some minor well-documented cajoling being needed, Eudora runs well in Windows XP through to Windows 10. Its power and usefulness more than compensate for its quirkiness, which includes not forwarding HTML-based emails very well, nor displaying MS Office 'smart quotes' due to the only character set (ISO 8859-1) that Eudora fully understands; hence some inbound email is occasionally sprinkled with UTF-8 strings such as: 'as Iâ ™ve been awaiting the clientâ ™s feedback' in place of apostrophes. Eudora also nags me once a week about trusting Gmail secure certificates. However, no one has ever complained that they can't read my email, which Eudora drafts in Times New Roman – but I always see it on-screen as Verdana, which is fine by me!

In November 2015's *Net Work* I asked readers how they manage their own email in today's cloud-connected world. **Dave (G4UGM)** wrote that he pays for a Microsoft Office 365 Home subscription from Microsoft, which costs about £8.00 a month or £80/year. Five licences for Office are included, also offering Access and Publisher and 5 × 1TB of Cloud Storage. The cost is less than paying DropBox for much less storage, and about the same as 1TB of cloud space from Google, Dave says.

These costs represent very good value if you are happy to be locked into an open-ended subscription, and doubtless I am heading inexorably that way too. Dave told me, 'for those who have moved to Windows 10 that comes with 'Modern' apps for Mail and Calendar, these both talk to Hotmail / live.com / outlook.com and are probably OK for lighter modules.' He also suggested the interesting-looking eM Client, available free for personal use from **www.emclient.com**. Unless you are committed to using Microsoft Office, I suppose users will likely adopt Gmail or Outlook.com by default. Also consider downloading Windows Live Mail software as part of Windows Essentials 2012, free from **http://windows.microsoft.com/en-gb/windows-live/essentials**.

One thing is becoming very clear: email is now a commodity service with little to distinguish between key players as they jostle to outdo each other. Today's users want to sync mail across phones or tablets while on the go, and who cares if it's managed out on the cloud somewhere? I'm in no doubt that offline programs like Eudora will gradually become too unrewarding and tiresome to use, especially when ISPs change their mail systems to the point that email software is finally rendered incompatible. Until then, Eudora is a key member of the staff here at *Net Work*, and I've just stuck it onto a brand-new machine.

Get Windows 10 – get gone!

One nearby PC on my home network still runs Windows XP, along with all the security worries that it brings. I spotted an

Asus desktop PC on the High Street for a knockdown price – one that I reckoned I could not build a Windows 8.1 PC for – and I was soon heading home with it tucked under my arm. Setting it up, I was struck by how desktop PCs are evolving: wireless 802.11ac networking is now built in, making PCIe Wi-Fi cards and USB dongles things of the past. Bluetooth is built in too, and this Asus PC is fuel-efficient with a low-voltage laptop-style switched-mode adaptor hooked on a power cord. HDMI video is standard, but DVI is nowhere to be seen, so a Startech HDMI-DVI adaptor sourced off Amazon ensured it would work with the year-old LCD monitor that I had in mind.

It was straightforward to connect the PC onto my home Wi-Fi – admittedly, Windows 8.1 made this task simple, marred only by its flat and featureless 2D GUI, which has not grown on me by one iota. Next, Avast Antivirus was installed before the torrent of endless Windows 8 updates arrived, taking six hours in total. Firefox followed and email was next, and the afore-mentioned Eudora 7 dropped straight in without a hitch. Browser Favorites (Bookmarks) were easily imported and the sprightly new machine was soon humming along on the network. A critical task is to create a Restore image which needed a branded 32GB USB3 memory stick that one can only hope will not be corrupted or zapped by ESD over time.

It wasn't long before the beguiling 'Get Windows 10' nag screen put in an appearance. Opinions vary wildly, but many PC users have taken the plunge recently with few regrets. However, for those who still find Windows 7 more productive, the leap to the flat, tiled, blocky and counter-intuitive Metro-style GUI is proving one step too far, at least for now. Regular *Net Work* reader **Dr Stephen Alsop** agrees, he says: 'I enjoyed your November 2015 column and you expressed my exact same problems and frustration following upgrading(?) to Windows 10. I have updated my four machines and I have never come across a more amateurish user interface. It really is a backward step. I had the same problems of simplistic, basic, poorly coloured windows and you could not tell which was the active one; window positions being lost between sessions, a hopeless Start menu, Outlook not sending emails, etc…

'I recommend the following utilities to get Windows 10 as near to W7 as possible, as without them I would have reverted back to Windows 7:

- WinaeroTweaker [**winaero.com**] – set coloured window bars and much more, I like this app
- Ultimate Windows Tweaker 3 – you can tweak everything, but it can upset a few settings, so do a system backup before using any of these. [*Now Version 4, from* ***TheWindowsClub.com*** *– ARW*]
- Classic Start Menu and ShellFolderFix are excellent to set the start menu and for saving folder and icon positions like they should be.'

Thank you for those tips – with 'Get Windows 10' becoming an irritation on my existing Windows 7 machine, I set about disabling this unwanted feature altogether. Microsoft disguises it under the cryptic name of 'GWX', so if you can temporarily end the nagging by disabling **GWX.exe** in Task Manager. It's Windows Update KB3035583 that results in the Get Windows 10 icon (see: **https://support.microsoft.com/en-us/kb/3035583**) and it can be uninstalled via `Control Panel/ System and Security/ Windows Update/ Installed Updates`. However, it will simply be downloaded again unless you also find and tick the option to permanently 'hide' it, as Microsoft classes it as an 'Important Update'. After uninstalling and rebooting, the GWX icon disappeared for good.

That's all for this month. It's my pleasure to offer all readers compliments of the Christmas season and I look forward to bringing you more Internet developments in the New Year. You can email me at **alan@epemag.demon.co.uk**

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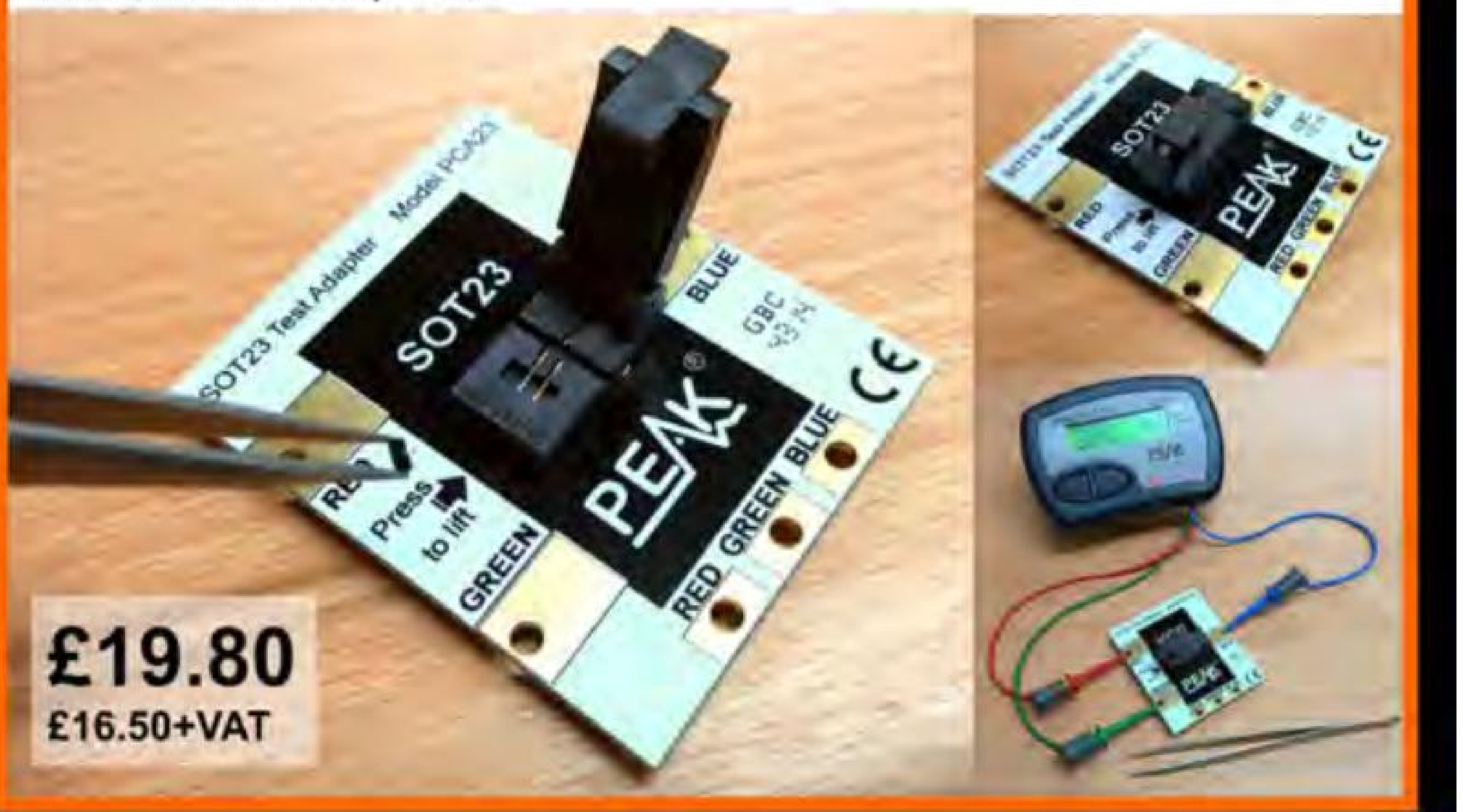
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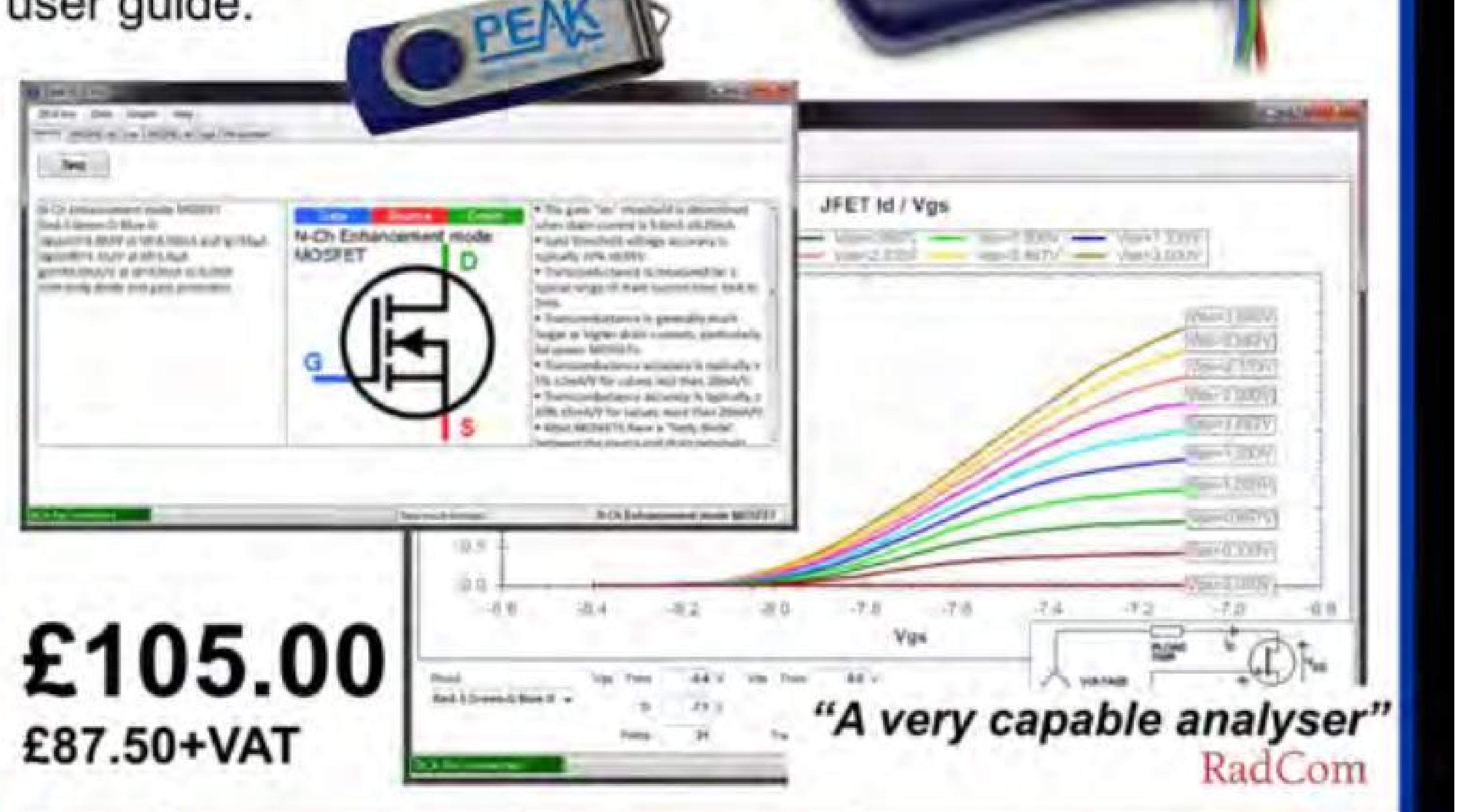
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BY IAN BELL

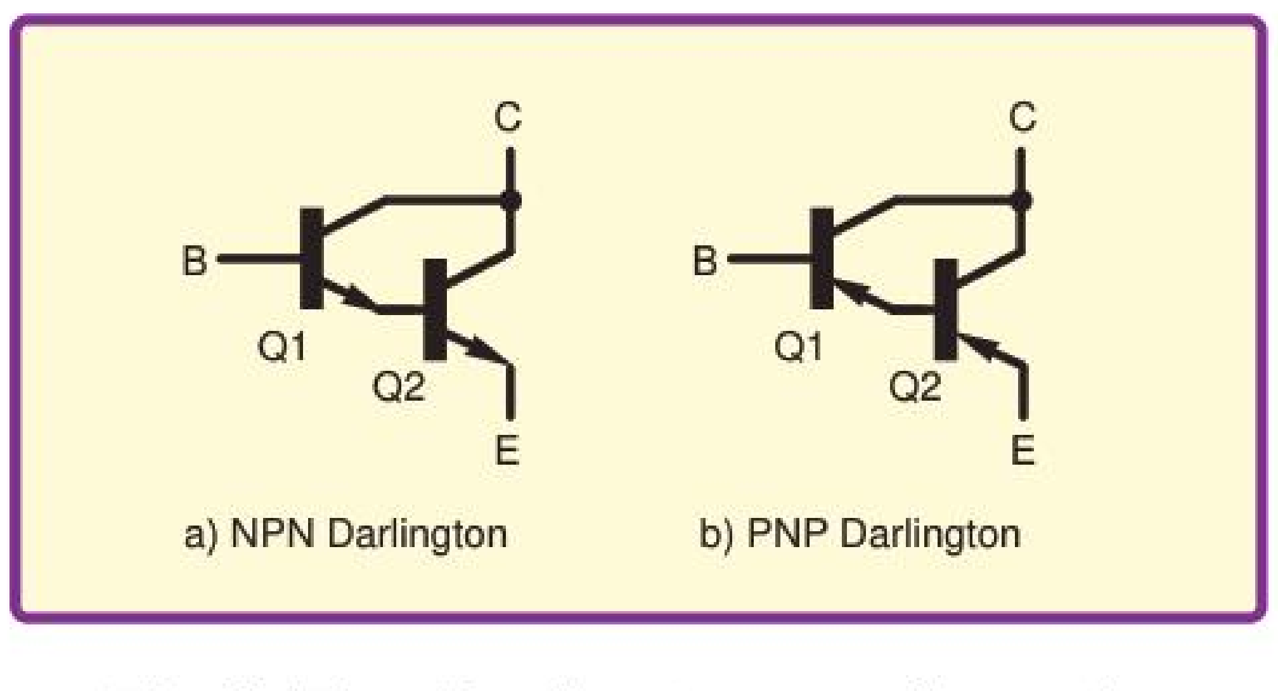
Darlington impedance

RECENTLY, frequent contributor ***lost*** posted the following question to the *EPE Chat Zone* forum: 'While looking for help with high-gain, high-input-impedance discreet-transistor voltage amplifiers, I came across an article which recommended the use of Darlington transistors. These, the article said, have high input impedance. It's not clear to me why that might be, and even if it's true, biasing arrangements will ruin it. What did I miss?'

Later, after another frequent contributor, ***james***, posted some useful simulation examples and there was some discussion of circuit configurations, ***lost*** added: 'The article I referred to had a grounded emitter, a 10k collector resistor and was biased by 100k from collector to base and was declared to have high input impedance. I stared at that for a while thinking, "if that's high Z-in there's something I don't know".'

The simple answer is ***lost*** is correct to point out that biasing arrangements may have an impact on circuit input impedance – and the particular circuit he describes has low input impedance. However, the Darlington configuration does provide higher impedance than a single transistor, but the right circuit must be used to exploit this. In this article we will look at the basics of Darlington transistors and similar arrangements, and then discuss Darlington input impedance, the actual circuit ***lost*** mentions and transistor amplifier input impedance.

Fig.1 shows both NPN and PNP Darlington circuits. In the Darlington configuration, one transistor is used to directly drive another, resulting in a sort of 'super transistor' with very high current gain (up to tens or even hundreds of thousands) and – of particular interest to ***lost*** – high input impedance. The Darlington is not the same as a 'superbeta transistor', which is a high-gain single transistor, achieved through fabrication means, particularly the use of a very narrow base region. At the risk of causing confusion the term 'superbeta pair' is sometimes used for the Darlington configuration. We are talking about 'beta' here because β is used as the symbol for transistor current gain (ratio of collector current to base current).



a) NPN Darlington b) PNP Darlington

Fig.1. The Darlington configuration

The Darlington pair behaves like a single transistor, but with twice the value of V_{BE} (ie, it has a higher switch-on voltage) and a current gain approximately equal to the *product* of the gains of the two transistors. The input resistance is increased by a factor comparable with the gain of the transistors. This is the input impedance of the compound transistor itself, the circuit in which it is used is another matter, as we will see later.

Darlington transistors (and similar arrangements, described later) are used in power switching applications, power amplifier output stages, voltage regulators and some types of sensing applications – particularly in optocouplers (the Darlington arrangement can be used to increase the gain of a phototransistor). They can also be used in the input and gain stages of amplifiers.

Applications and issues

Darlington transistors in a single package (including arrays of multiple Darlingtons) are readily available from a number manufactures, and have been around since the 1970s. These are mainly aimed at power handling and switching applications and may contain additional components to facilitate this. A typical example is given in Fig.2, which shows the equivalent circuit of the TIP120. This device includes a protection diode and a couple of resistors. The resistors act as pull-downs to make sure the transistor is off when required – this is particularly important if the drive circuit is high impedance when it is off. Note that the presence of the resistors means that devices of this type do not have high input impedance and are not suitable for all applications.

In high power applications, the first transistor (Q1) makes sure that the power transistor (Q2) receives sufficient base current to fully turn on. A high power transistor may require significant base current, which would not be readily available from the controlling circuit's output (eg, a logic output) if it were connected directly. Darlington pairs are very useful for switching high power loads from logic outputs – however, a word of caution is needed here because one disadvantage of the Darlington pair is that the configuration can be rather slow in switching. The problem is due to the fact that the first transistor cannot switch the second one off quickly – it goes open circuit leaving charge in the base of the second transistor, which takes time to shift. Connecting a resistor from the base of the second transistor to ground alleviates this problem (see R2 in the circuit in Fig.2).

In addition to the Darlington requiring double the switch-on voltage of a single transistor, and possibly exhibiting slow switching, there are other potential issues. First, all semiconductors suffer from leakage currents, and any leakage from the first transistor in a Darlington pair will be amplified by the second, meaning that total leakage effects may be quite large. Again, the R2 (Fig.2) base resistor helps – it is selected to ensure that its voltage drop when the first transistor's leakage current is flowing through it is such that the second transistor will not turn on.

Another issue with the Darlington is the collector-emitter saturation voltage – the voltage across the transistor when it is fully switched on. For a single transistor, this is about 0.1V to 0.3V (smaller than the typical V_{BE} of 0.6 to 0.7V). For the Darlington pair the saturation voltage is significantly larger, being equal to V_{BE} of the second transistor plus the saturation voltage of

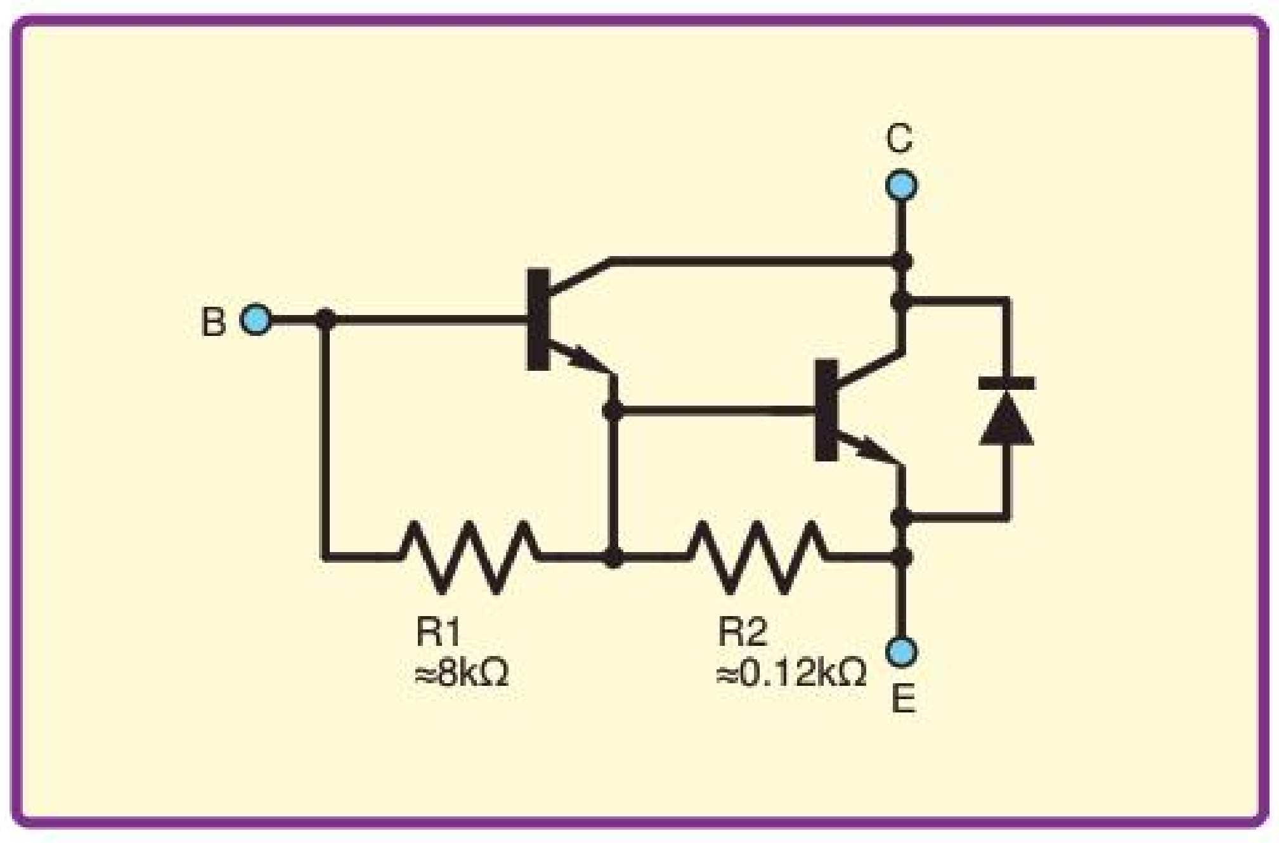


*Fig.2. Example Darlington power transistor internal circuitry. This is the TIP120 from the Fairchild datasheet (**fairchildsemi.com**)*

the first transistor. This is important in power switching applications because it results in greater dissipation due to the larger voltage drop across the device when it is on. In amplifiers, the signal may start clipping sooner than with a single transistor.

The Sziklai pair

Fig.3 shows a similar configuration to the Darlington, which is known as a Sziklai pair. One of the main features of this alternative compound transistor is that it only requires a single V_{BE} voltage to turn on. This gives the Sziklai pair the advantage of being able to be 'plugged in' in place of a single transistor. Furthermore, the lower effective V_{BE} makes it far easier to use in low-voltage circuits. This is an important concern in IC design, where only a small number of V_{BE} drops can be stacked before all the headroom of the supply is used up.

The PNP Sziklai pair has played a role in IC design for a long time, particularly in essentially NPN processes that allowed fabrication of good NPN transistors, but which only provided low-gain PNP transistors. The compound transistor provides a means of obtaining a high-gain PNP in these technologies.

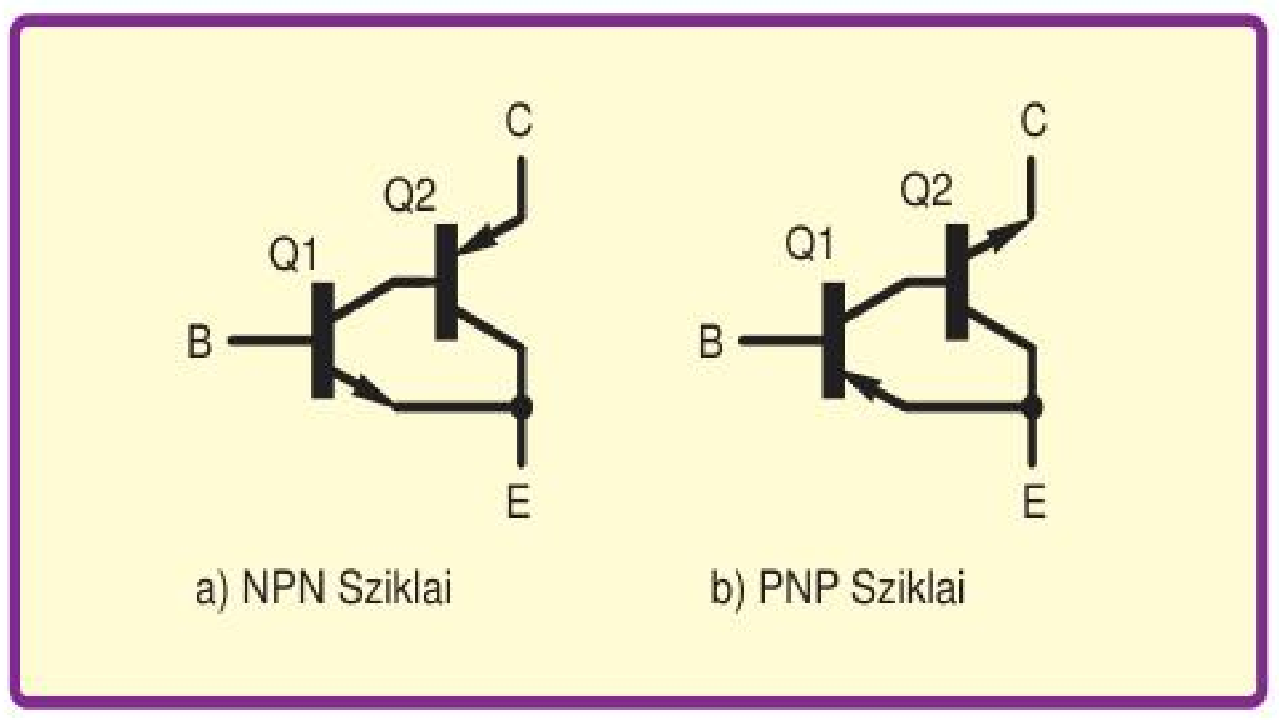


Fig.3. The Sziklai pair, or complementary feedback pair configuration

The Sziklai pair is typically biased using a resistor, as shown in Fig.4. R1 is selected so that most of the current in Q1 flows through R1 rather than the base of Q2. This means that the quiescent (no signal) current in Q1 is well defined and does not depend on the gain of Q2 and its collector current. The collector current of Q1 (I_{C1}) is approximately V_{BE2}/R1 if we assume that Q2 has a high enough gain for I_{B2} to be significantly smaller than I_{C1}. Typically, we want Q1 to have a quiescent current about one tenth of that for Q2; so, given this assumption, and given that we probably choose I_{C2} as a key design parameter, we get R1=10V_{BE2}/I_2, where, as usual, V_{BE2} would typically be between 0.6 and 0.7V.

A typical use of the Sziklai pair is in audio power amplifier output stages, where it is considered by many to deliver better performance in terms of thermal stability and large signal non-linearity due to the feedback effects within the transistors pairs (this configuration is also called a 'complementary feedback pair'), although these effects are reduced at high frequencies.

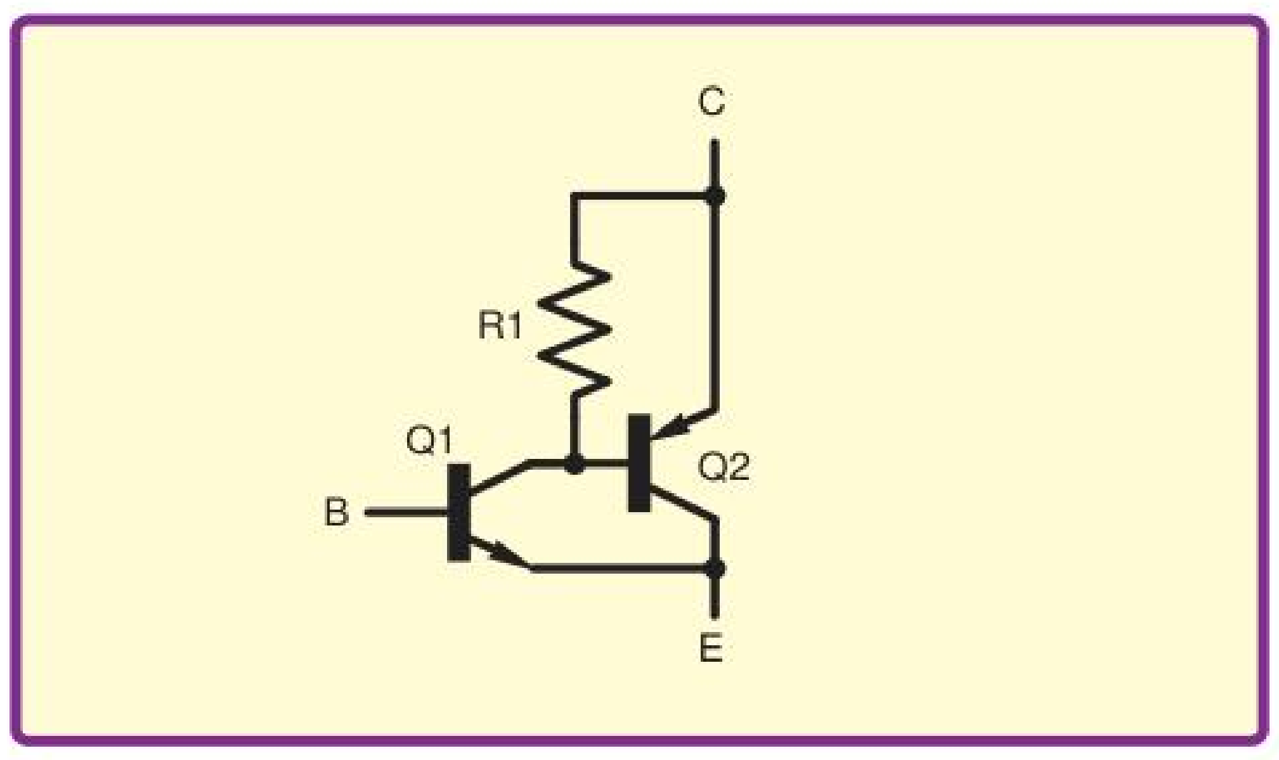


Fig.4. Sziklai pair with bias resistor

Small-signal models

Returning to ***lost's*** posting – why does a Darlington have high input impedance? We can show this is the case using a small-signal model of the Darlington circuit, comprising a simple model of the two individual transistors. The single transistor model is shown in Fig.5. This represents the transistor's response to a low-level signal varying around a particular operating (bias) point. The actual bias currents and voltages are not included in the model (hence the term 'small signal'); however, the bias conditions set the values of the model parameters.

The small-signal model is linearised to make it easier to work with than the exponential (non-linear) equations which are required if large signal ranges are to be accounted for. This is why we can represent the base-to-emitter connection as a resistance (as shown in Fig.5) rather than a forward-biased diode (which it really is). In the model, r_{be} represents the resistance of the base-emitter PN junction (diode) at the particular operating point at which we have biased the transistor. Diode resistance varies with current – specifically the resistance is inversely proportional to current – the higher the current in the diode, the lower its resistance. We see this in the diode current-voltage characteristic – the curve gets steeper (lower resistance) as the applied voltage and hence operating point current increases.

Thus, both r_{be} (input resistance) and r_o output resistance decrease in proportion to increased collector bias current. For each transistor in a circuit design we typically choose a collector operating point based on considerations such as the current at which the transistor performs best, load drive requirements and power constraints. For the Darlington pair, setting the bias current in one transistor determines the current in the other – they are directly related because the emitter current of the first transistor is the base current of the second. The current in the second transistor's collector is β_2-times larger than the collector current in the first transistor, where β_2 is the current gain of the second transistor. This means that the input and output resistances of the first transistor are β_1-times larger than those of the second transistor; for example, $r_{be1} = \beta_1 r_{be2}$.

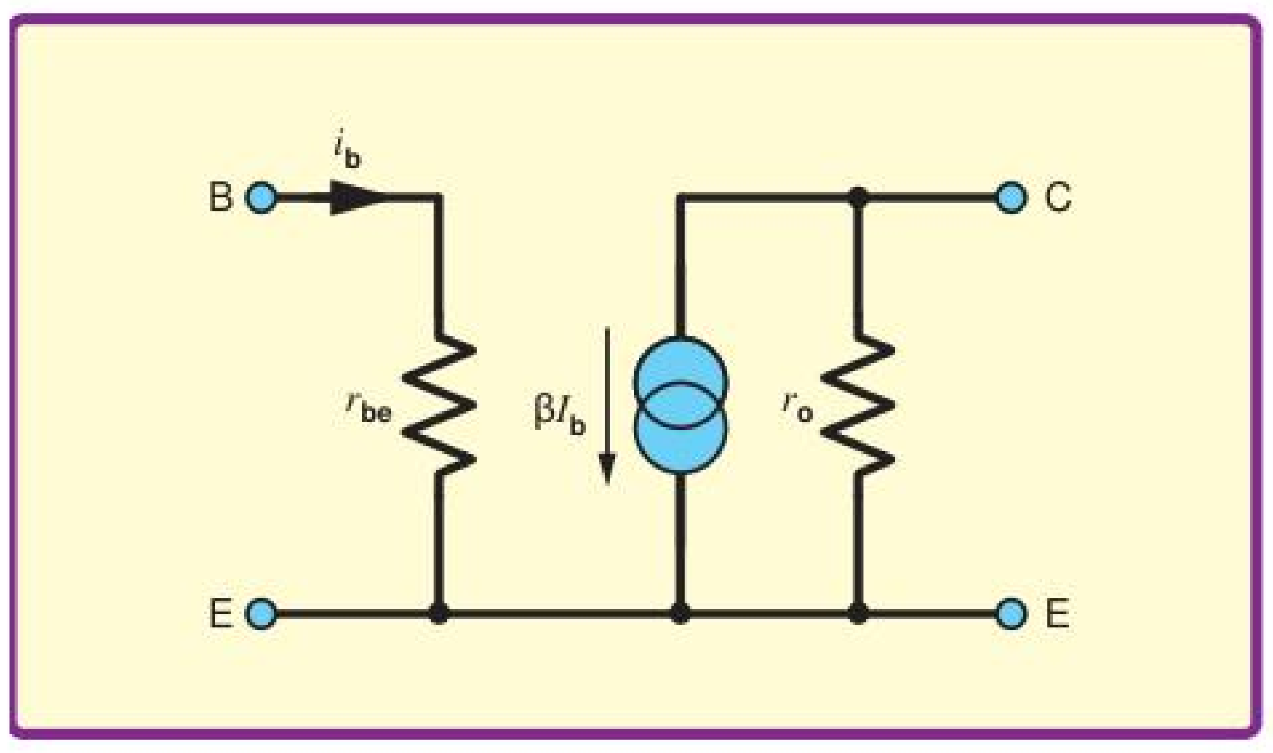


Fig.5. Small-signal model of the bipolar transistor in common-emitter configuration

The variation of β with bias current is not so straightforward. For each transistor there will be a collector current at which β is maximised. So, note that if the two transistors are both the same then it is unlikely that they can both be at the optimal collector current. For our purposes we can just assume two different β values.

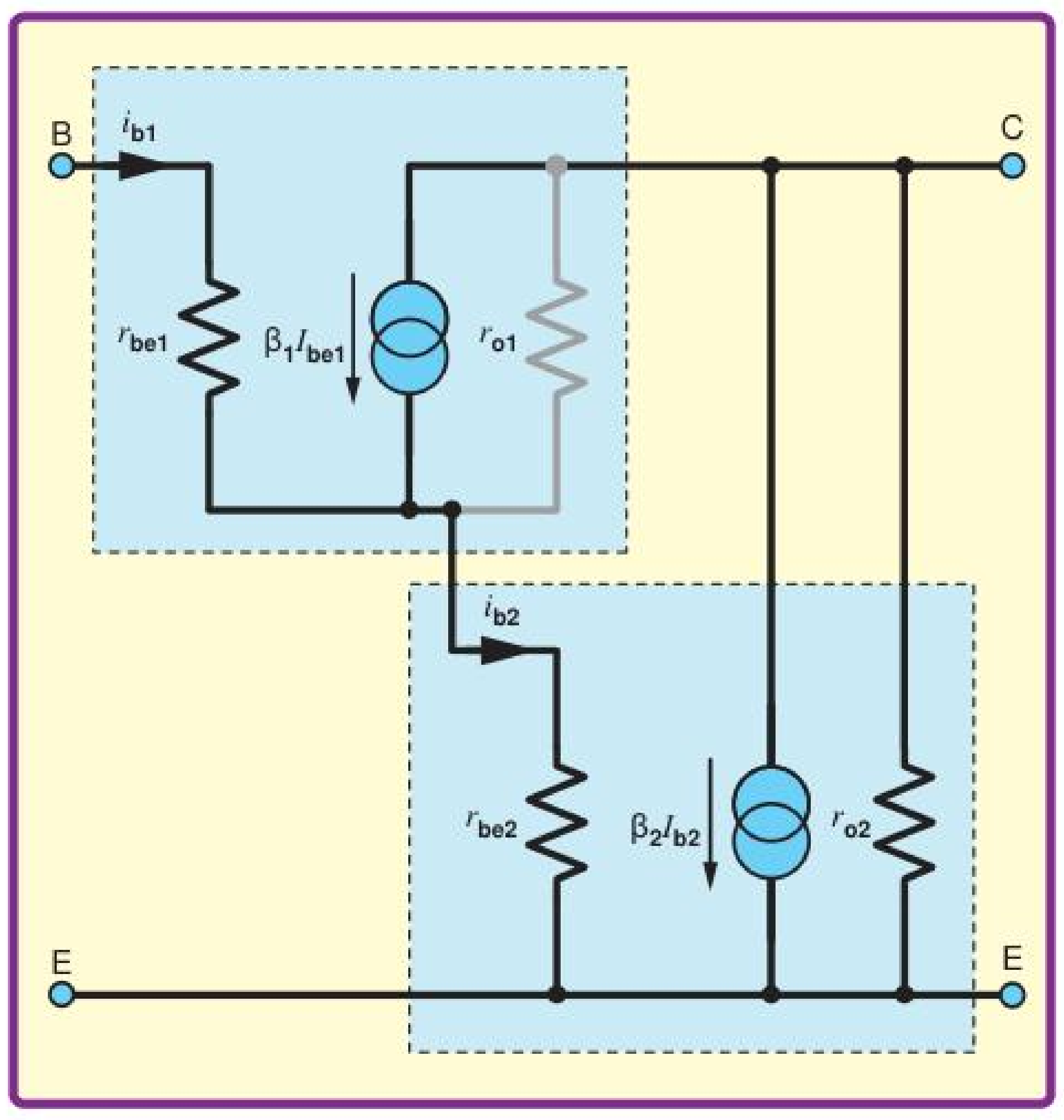


Fig.6. Small-signal model of the Darlington pair

Darlington impedance

We can find an approximate expression for the input impedance of the Darlington transistor using the equivalent circuit in Fig.6. This uses two copies of the model in Fig.5 connected in the Darlington configuration. To simplify things we will ignore the output resistance of the first transistor. We then have an input current of i_{b1} and voltage at the input equal to the sum of the drops across r_{be1} and r_{be2}. The current in r_{be1} is i_{b1}, so the voltage across it is $i_{b1}r_{be1}$. The current in r_{be2} is $i_{b1} + \beta i_{b1}$ so the voltage across it is $(1+\beta_1)r_{be2}i_{b1}$. The voltage at the input is the sum of these:

$$v_{in} = i_{b1}r_{be1} + (1+\beta_1)r_{be2}i_{b1}$$

If we divide the input voltage by the input current we get the input resistance, which is:

$$r_{in} = v_{in}/i_{in} = r_{be1} + (1+\beta_1)r_{be2}$$

Previously, we noted $r_{be1} = \beta_1 r_{be2}$, so the resistance can be written:

$$r_{in} = \beta_1 r_{be2} + (1+\beta_1)r_{be2}$$

Assume β_1 is much larger than 1 (it is typically 50 to 200), then we can ignore the 1 in $(1+\beta_1)$, so we arrive at approximate input resistance of:

$$r_{in} = 2\beta_1 r_{be2}$$

Thus, compared to a single transistor running at the same bias collector current as the second transistor in the Darlington configuration, the Darlington pair has significantly larger input impedance.

Shunt feedback amplifier

Now that we have covered the background of the Darlington transistor, we move on to look at ***lost's*** circuit, or more accurately, the one from the article to which he refers (unfortunately, he does not reference or link the article, so we do not know any further details). A schematic *based* on ***lost's*** written description is shown in Fig.7b. This circuit is a standard amplifier circuit, known as a shunt feedback amplifier, which is usually built using a single transistor, as shown in Fig.7a. The resistor R_F acts as both a feedback resistor and supplies bias current to the transistor.

A key thing we should note is that the shunt feedback amplifier is fundamentally a trans-impedance amplifier – that is, it has an input of current and an output of voltage. Because the circuit has a current input, its input impedance is ideally zero – obviously not the high impedance that ***lost*** is looking for! If we assume the transistor (single or Darlington) and collector resistor, R_C, in Fig.7 form a perfect voltage amplifier, then the whole circuit is equivalent to an op amp trans-impedance amplifier, see Fig.8. This is illustrated in Fig.9, where the schematic of Fig.8 has been redrawn to show how Fig.7b corresponds to Fig.8.

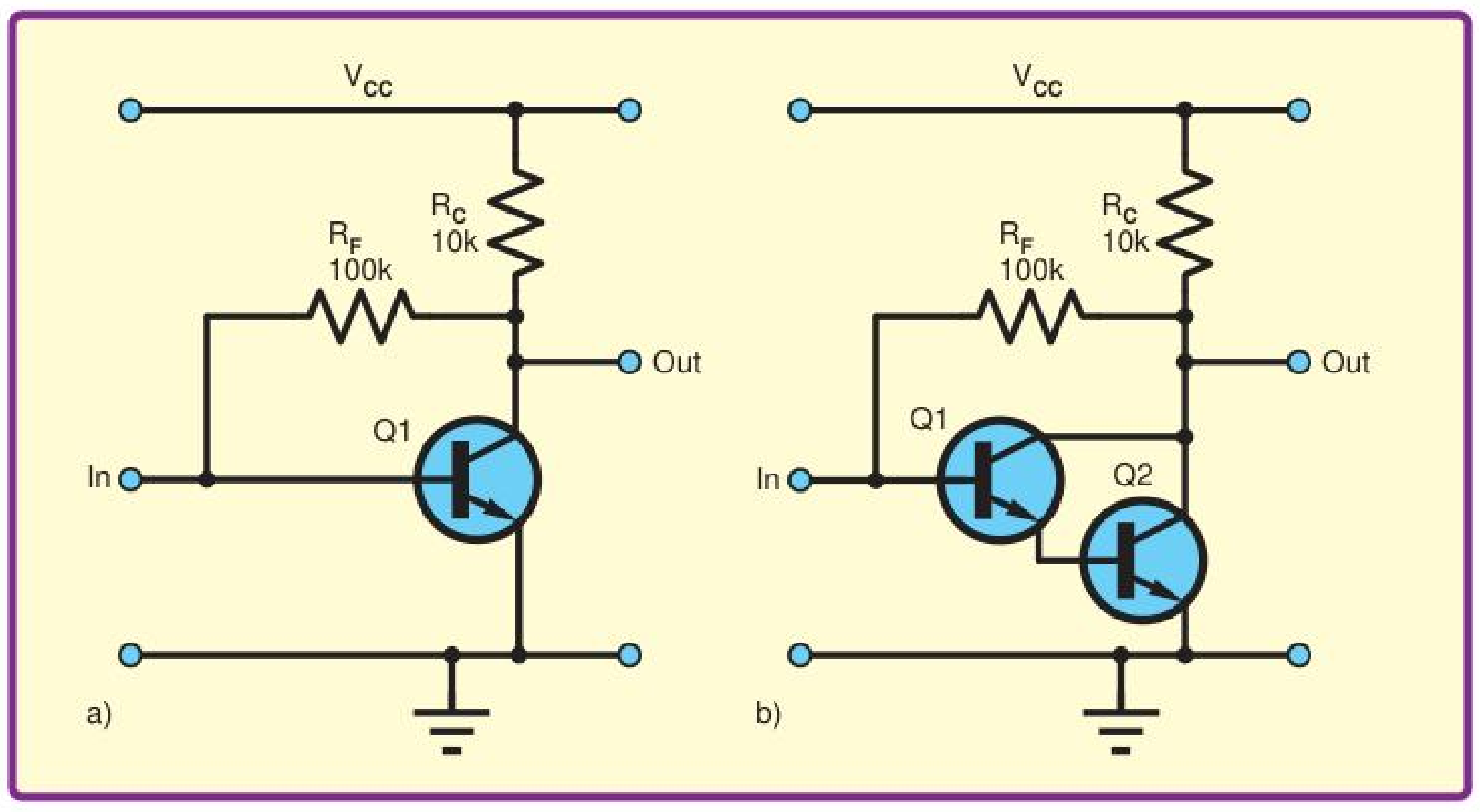


Fig.7. Shunt feedback amplifier (a) single transistor (b) Darlington version

We can make a voltage amplifier from the trans-impedance circuits in Fig.7 and Fig.8 simply by adding an input resistor. Starting from the circuit in Fig.8, this gives us the well-known op amp inverting amplifier configuration shown in Fig.10. The voltage gain is $-R_F/R_{in}$. If the 'op amp', whether it is really just the transistor and R_C, or an actual op amp, has a high voltage gain then its inverting input will stay close to 0V. The inverting input then behaves like a ground connection – called a virtual earth. With this assumption it is straightforward to find that the input impedance is equal to R_{in} (this resistance is connected directly from the input to the virtual earth).

Simulation

We can simulate the circuit in Fig.7b to confirm the above arguments. With R_F = 100kΩ, choosing R_{in} = 10kΩ should give a gain of 10 and an input impedance of 10kΩ. The circuit in Fig.11 was used for an LTSpice simulation. Both the single transistor and Darlington versions were simulated.

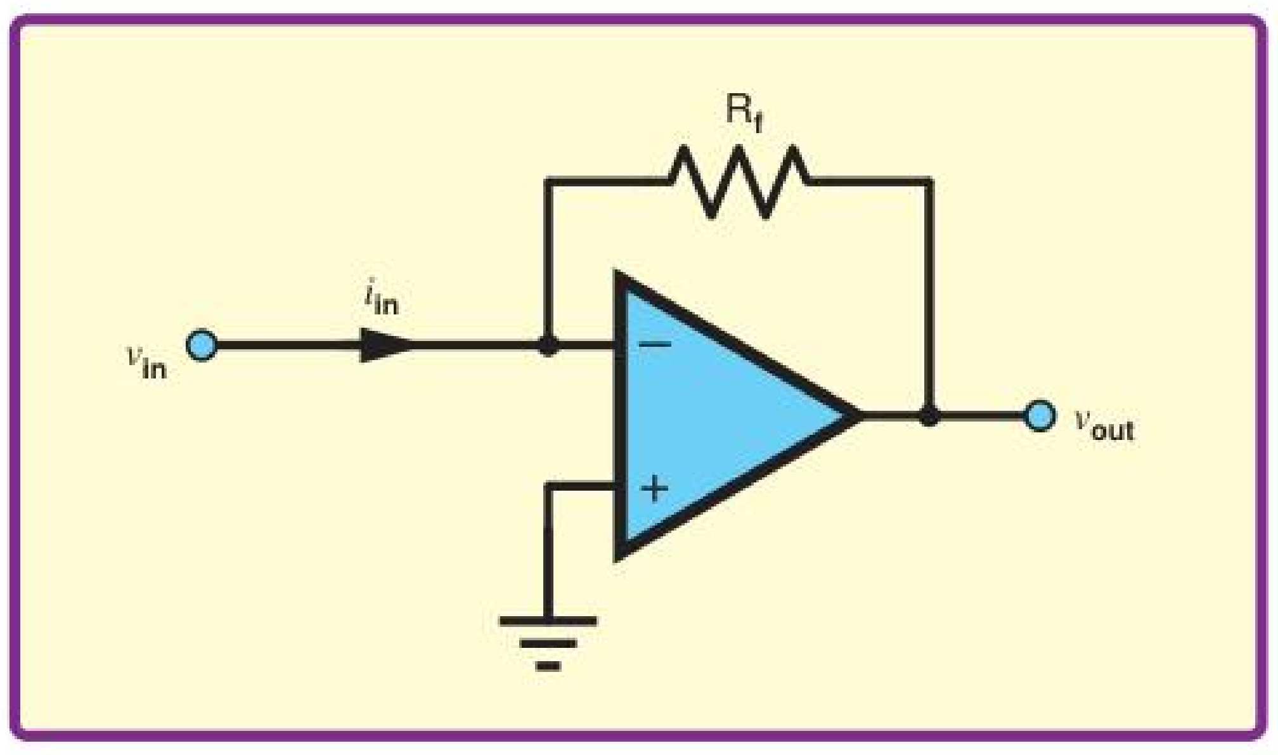


Fig.8. Op amp trans-impedance amplifier. Gain is $-R_f$, input impedance ideally zero

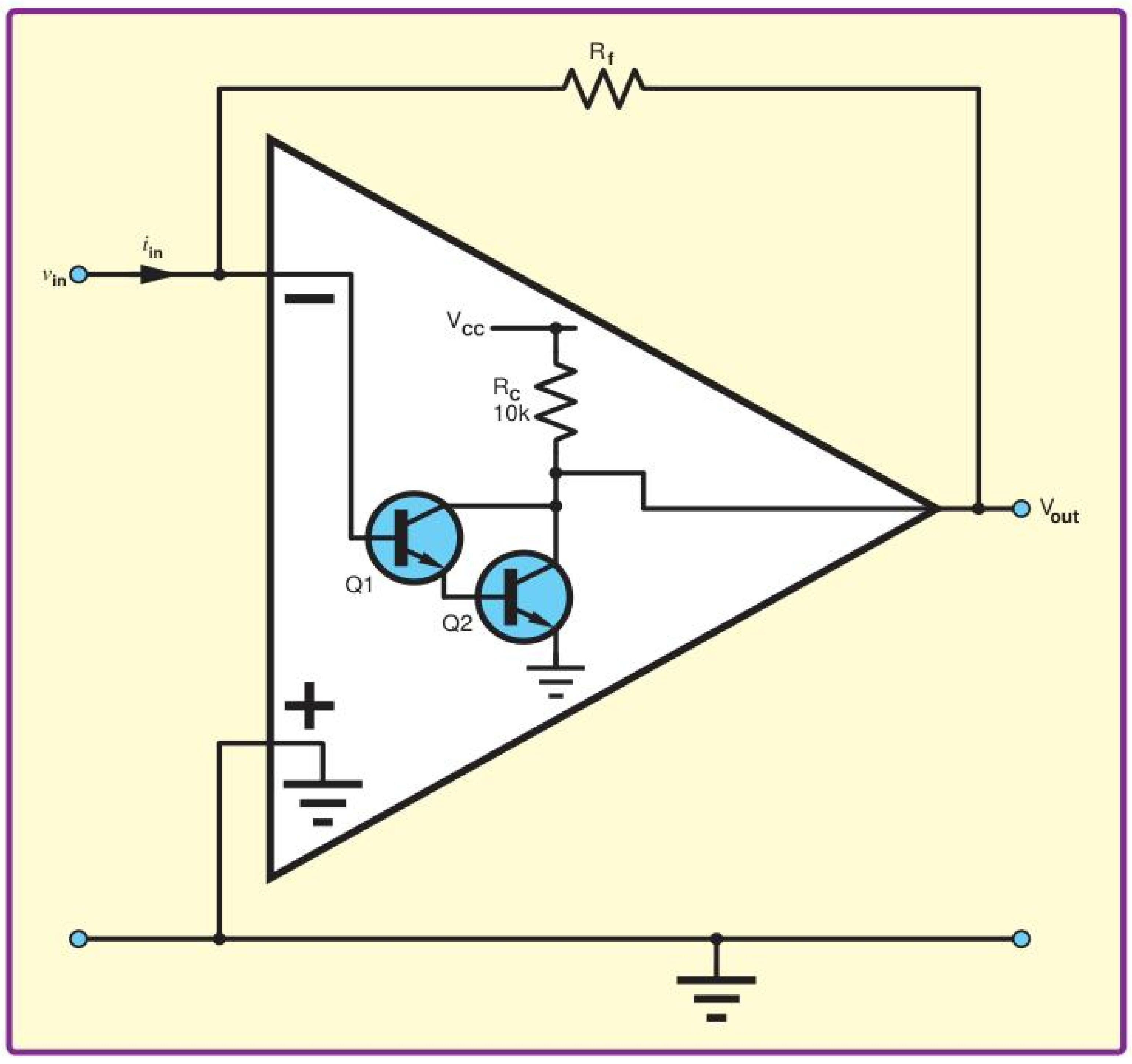


Fig.9. Correspondence between circuits in figures 7b and 8

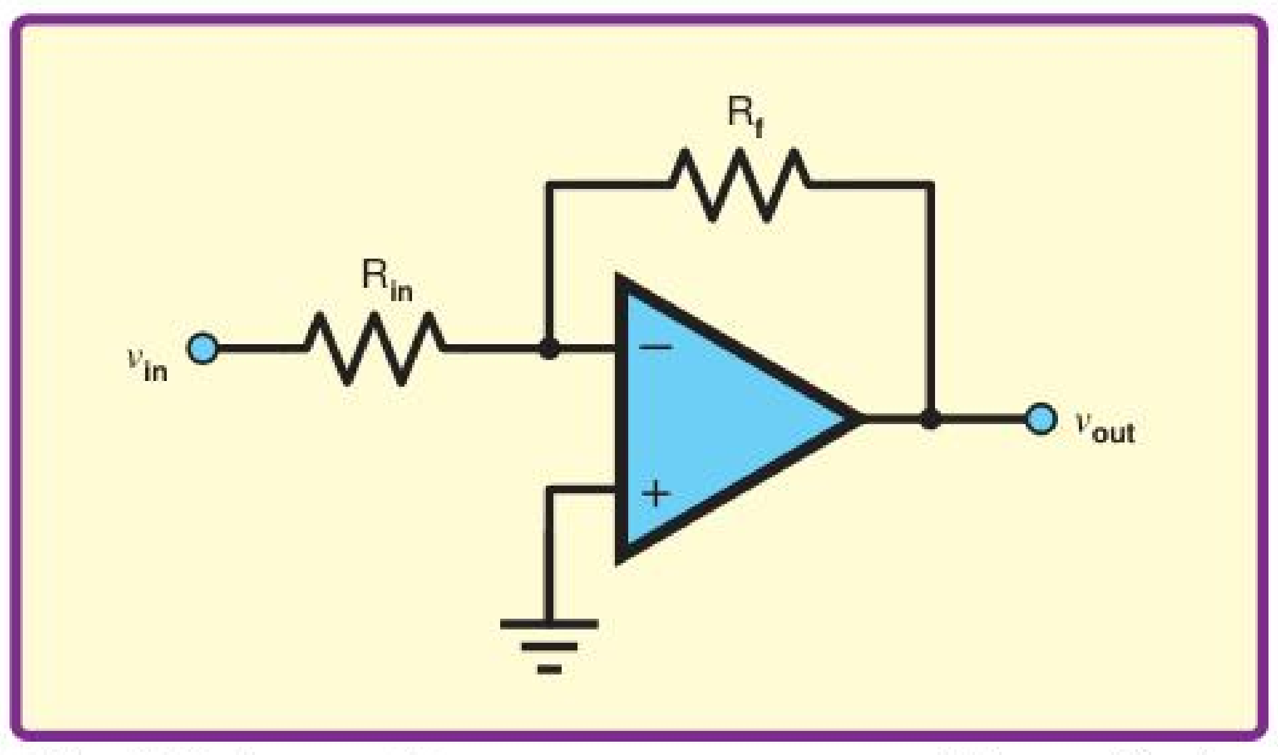


Fig.10. Inverting op amp amplifier. Gain R_F/R_{in}, input impedance R_{in}

A plot of the gain from 10Hz to 100kHz for both circuits is shown in Fig.12, in which a linear gain scale rather than the usual decibels is used. A plot of the input resistance (input voltage divided by input current) over the same range is shown in Fig.13. These results show that for both circuits the gain is close to 10 and the input resistance close to 10kΩ. The gain is less than ten because the open-loop voltage gain of the transistor plus R_C (our pseudo op amp) is not particularly large, so the approximation of the gain to R_F/R_{in} is not particularly good. The input resistance is a little larger than 10kΩ because this shunt feedback amplifier is not ideal – it does not have zero input resistance. The coupling capacitor also contributes impedance at low frequencies.

We can also perform a transient simulation and look at the output waveforms. An example is shown in Fig.14. Here we see the Darlington version of the circuit clipping the waveform below about 0.7V, whereas the single-transistor version is not clipping the signal at levels below 0.4V. This problem with the Darlington circuit is due to its large saturation voltage, which we discussed earlier.

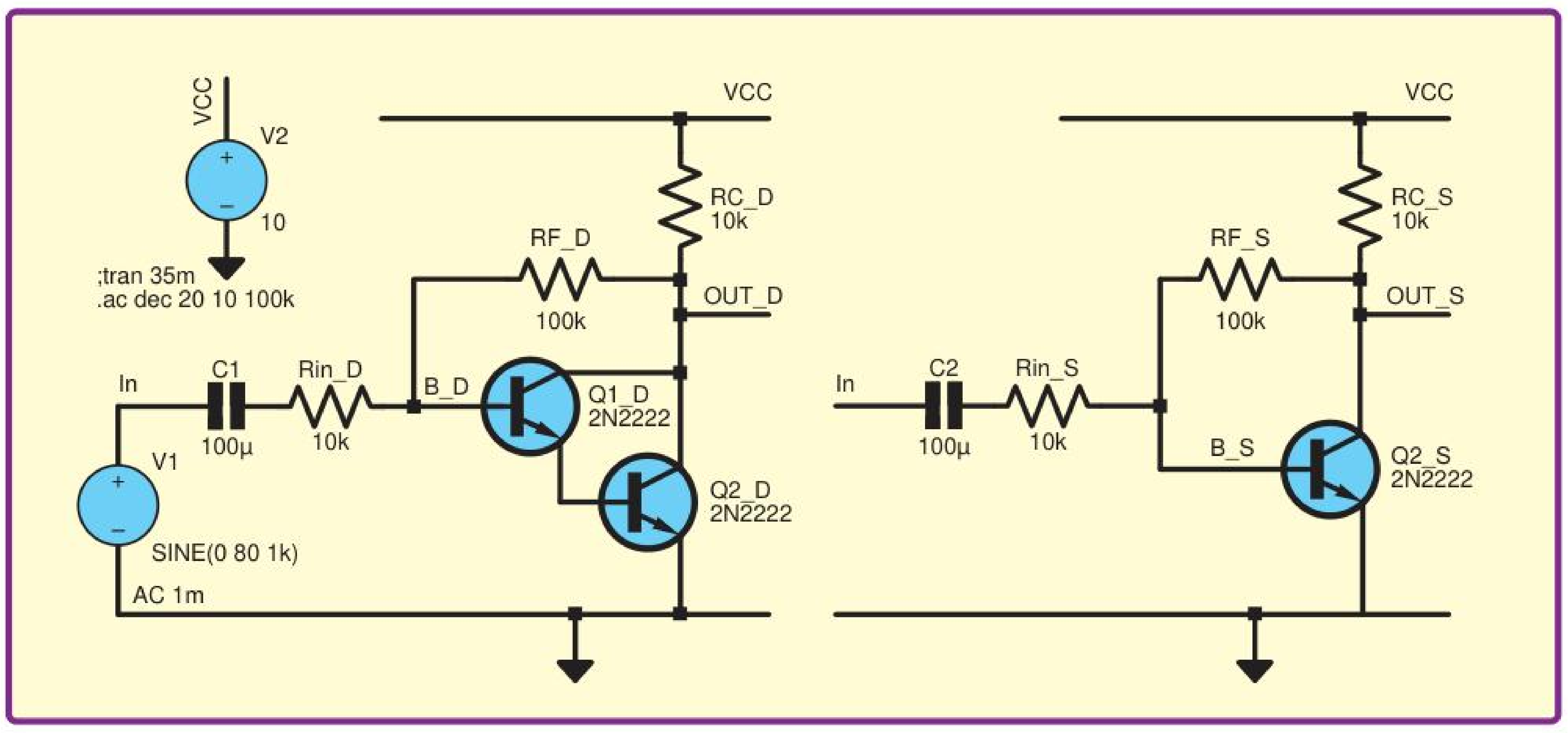


*Fig.11. LTSpice simulation schematic for investigating **lost's** circuit*

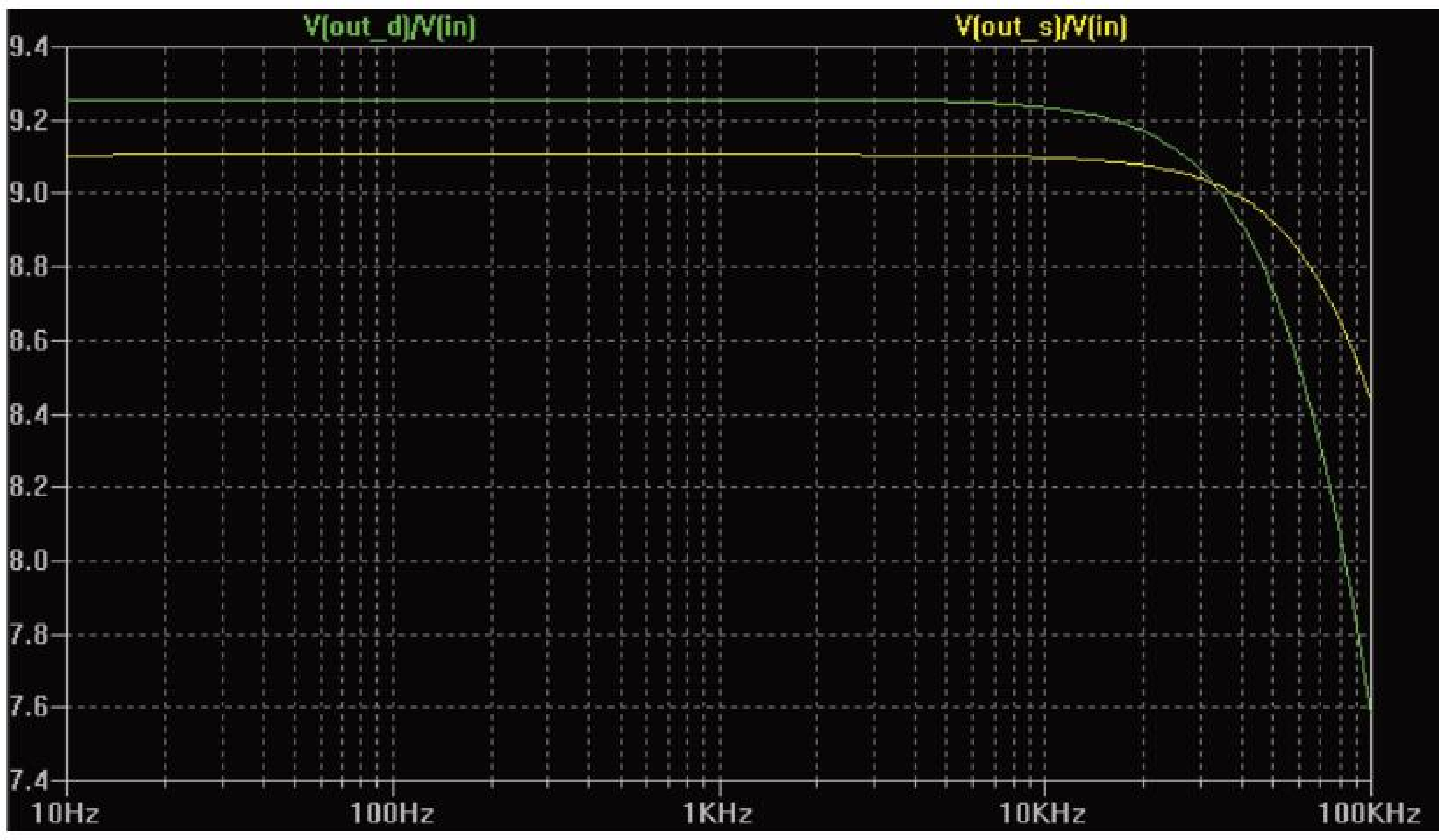


Fig.12. Gain of circuits in Fig.11 against frequency. Darlington green trace, single transistor yellow trace

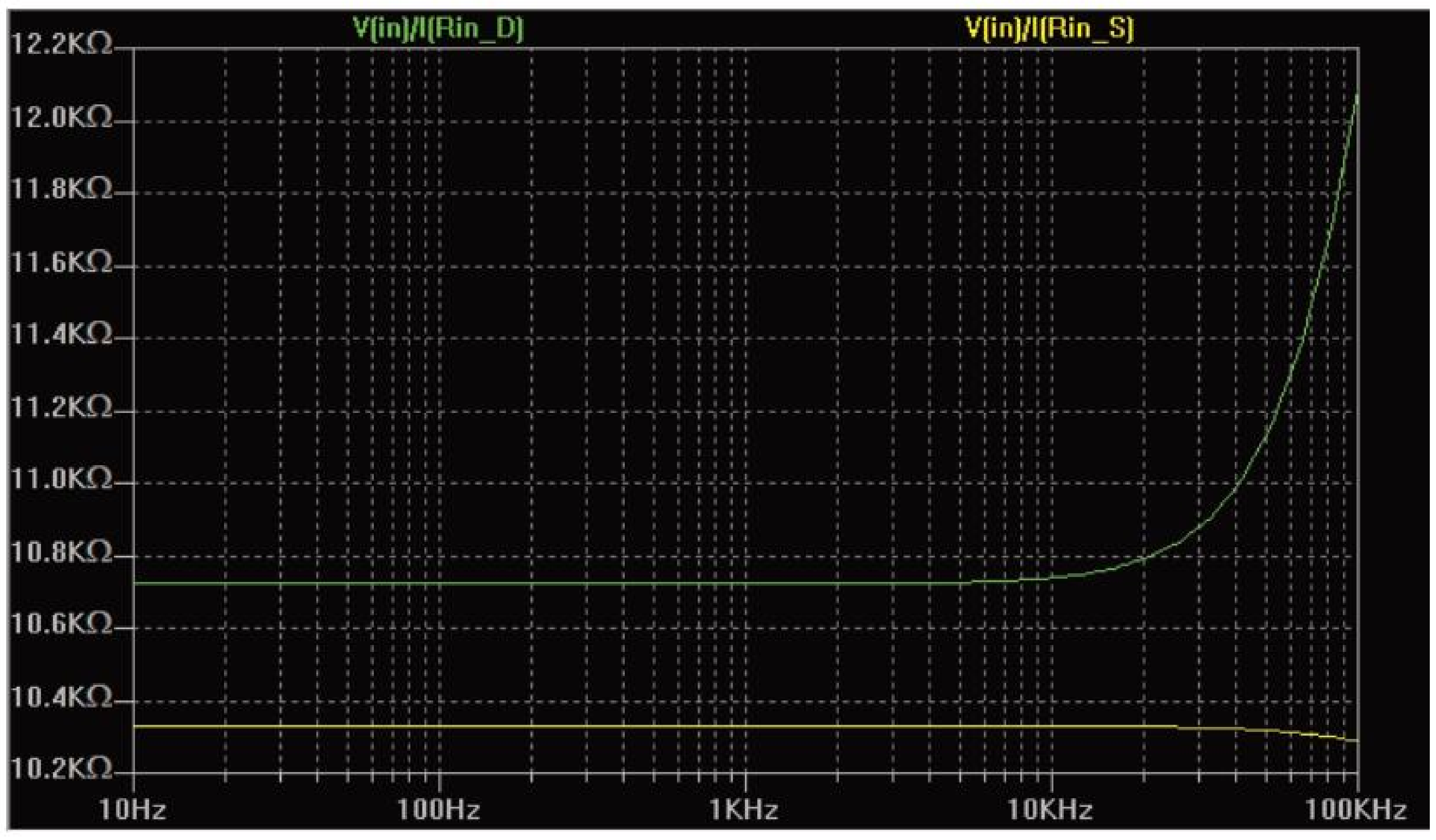


Fig.13. Input resistance of circuits in Fig.11 against frequency. Darlington green trace, single transistor yellow trace

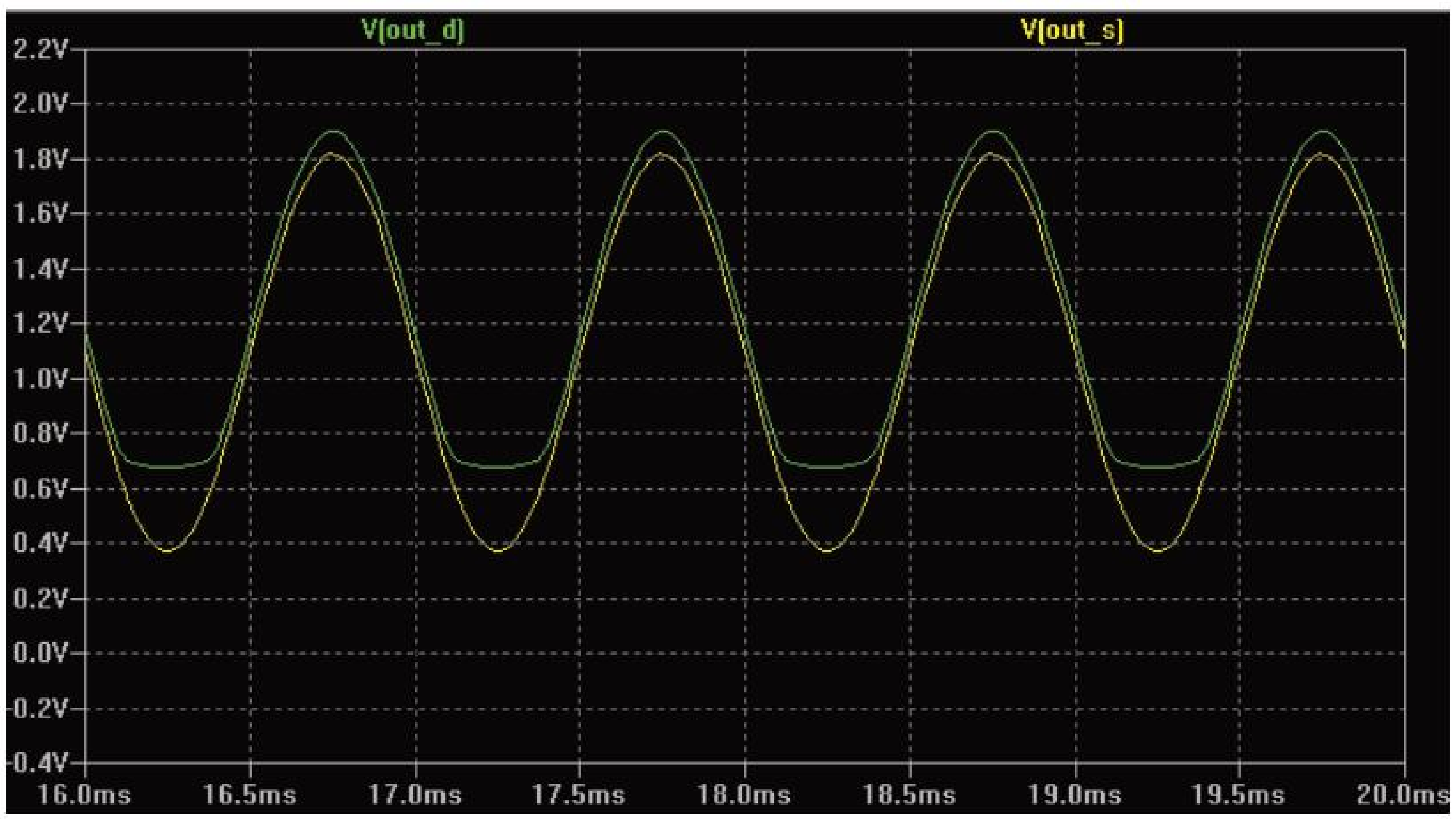


Fig.14. Output waveform for the circuits in Fig.11. Darlington green trace (exhibiting clipping), single transistor yellow trace

Biasing

Our investigation of this circuit indicates that it does not have high input impedance and does not really make good use of the Darlington transistor. We can do better by using a Darlington in place of the single transistor amplifier with potential divider bias, as shown in Fig.15. Similarly, we can also use the Darlington in an emitter-follower circuit, although, of course, the voltage grain is unity. In both cases, the bias resistors will dominate the input impedance.

The rule of thumb for the circuit in Fig.15 (and the emitter follower biased in the same way) is that R1 and R2 should carry at least ten times the base current required by the transistor, so that the base bias voltage is sufficiently 'stiff'. Here we can gain some advantage from a Darlington in that the resistors can be much larger due to the lower base current demand (assuming the same collector current bias). However, they still appear in parallel with the input and reduce the total input impedance compared to that of the Darlington itself.

Bootstrapping

The problem with the bias resistors dominating the input impedance can be overcome using bootstrapped biasing. This is illustrated in Fig.16, again for a single transistor, but a Darlington could be used too. The circuit in Fig.16 is the same as that in Fig.15, but with the bootstrap components R_B and C_B added (the same approach can also be used with an emitter follower). As far as DC is concerned, there is little difference between the two circuits as long as R3 is small enough for the voltage drop due to the bias current flowing through it to be relatively insignificant (the bias current is small, so this is not too challenging).

For AC – that is, for the signals we are amplifying – the circuit in Fig.16 is significantly different from that in Fig.15 due to the feedback provided by capacitor C_B, which is connected to the transistor's emitter. The voltage here follows the input signal with close to unity gain, although the DC levels are different with the emitter being at a voltage one V_{BE} drop (two for a Darlington) below the DC level at the base. This means that, as far as the *signal* is concerned, the *same voltage* occurs at both sides of R_B. The very small signal voltage drop across R_B implies that very little signal current flows through it; so it has very high impedance as far signals are concerned. If the gain of the circuit from the input to the emitter were exactly unity, then R_B would have infinite impedance to signals. Thus R_B, under the influence of the feedback from C_B, effectively isolates the signal from the bias resistors. The bias resistors no longer contribute (so much) to the input impedance, which now depends more on the transistor and potentially facilitates the exploitation of the high input impedance of the Darlington.

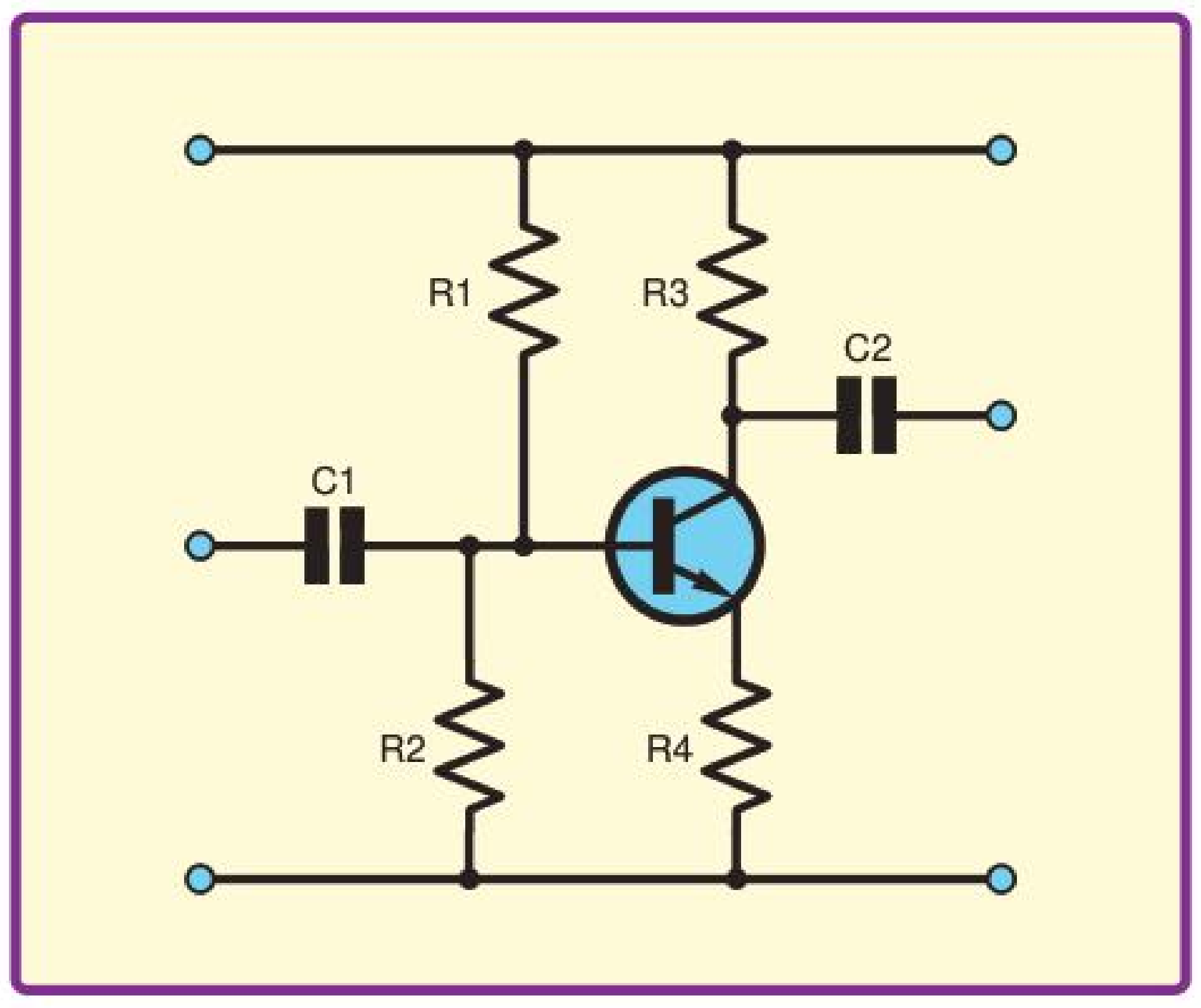


Fig.15. Single-transistor amplifier with potential divider bias. Using a Darlington in place of the single transistor allows larger values of R1 and R2 to be used, increasing input impedance

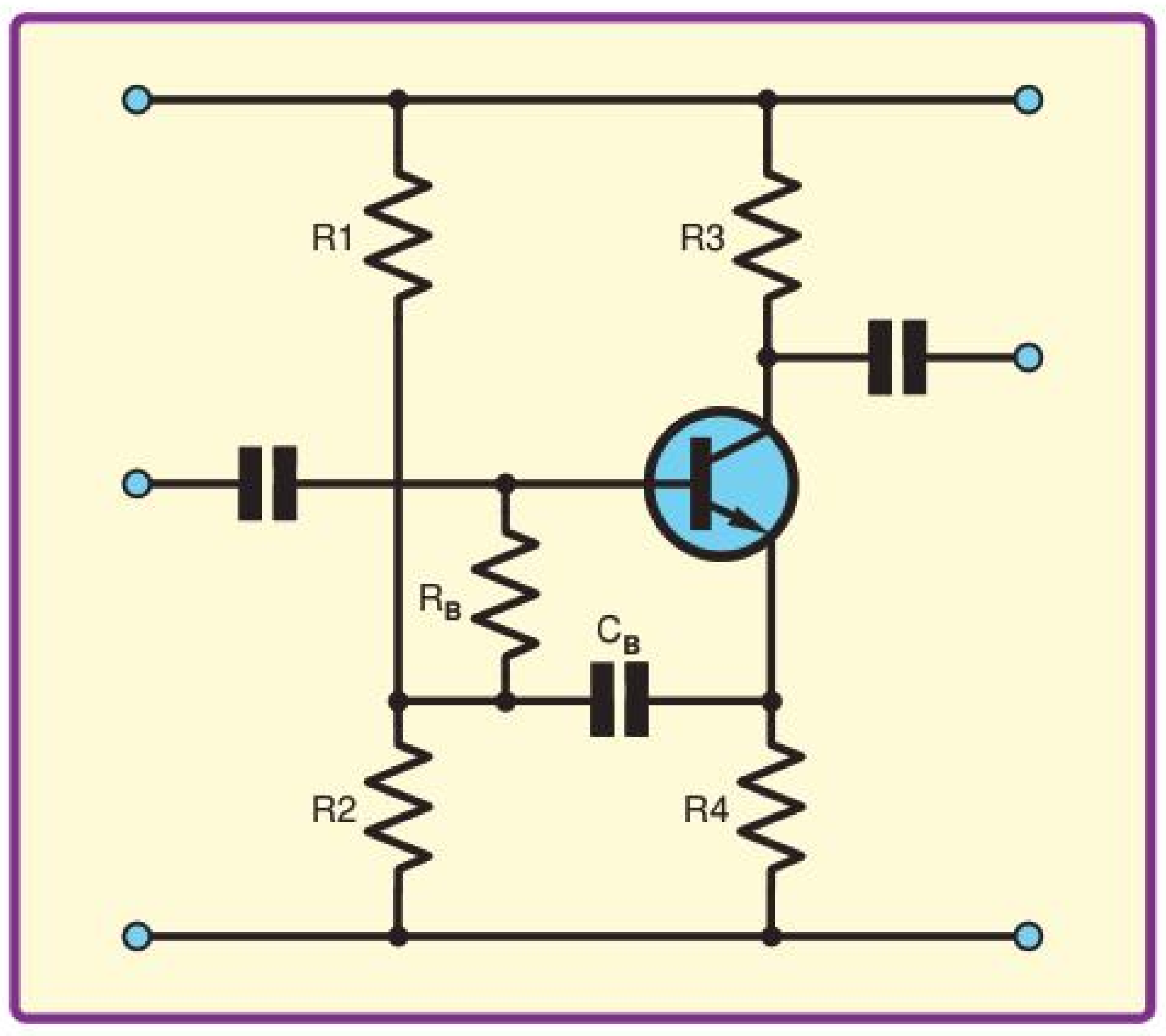


Fig.16. Bootstrap biasing

The preceding discussion shows that the Darlington transistor has high input impedance, but appropriate circuit design is required to fully exploit this. We have not looked at all the possibilities; for example, another approach is to use a Darlington in a differential pair circuit. To make a single input amplifier we can just ground one of the inputs. In all cases, the Sziklai pair may provide superior performance to the Darlington.

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICmas Tree

WE'RE approaching Christmas, and the time to put up decorations! So, I figured it only appropriate to have a little project that would bring festive cheer as well as keeping you busy in the run up to the holiday season.

Last month, we looked at *How to pick a PIC* and compared Microchip's 8-bit, 16-bit and 32-bit offerings. This month, we're going to build a *PICmas Tree*. Inspired by 4 × 4 × 4 LED cubes (for example, see: **http://tinyurl.com/p4n6v7p**), which seem to be popular at the moment, I thought why not change it's shape to something seasonal, like a Christmas tree. I know you might be thinking that this has been done before and it's a bit easy. However, I've worked extra hard on this one to pose a bit of a challenge in soldering, wiring and technical complexity. I want to drive 56 LED's using our readily available PIC18F27J13 (See the *LPLC* boards from previous articles, available for purchase at: **www.mjhdesigns.com**). This PIC has only 23 GPIOs, so here's the challenging part – I want to drive each of those LEDs, individually using only eight GPIO pins. In order to do this, we need to look at how we normally drive LEDs.

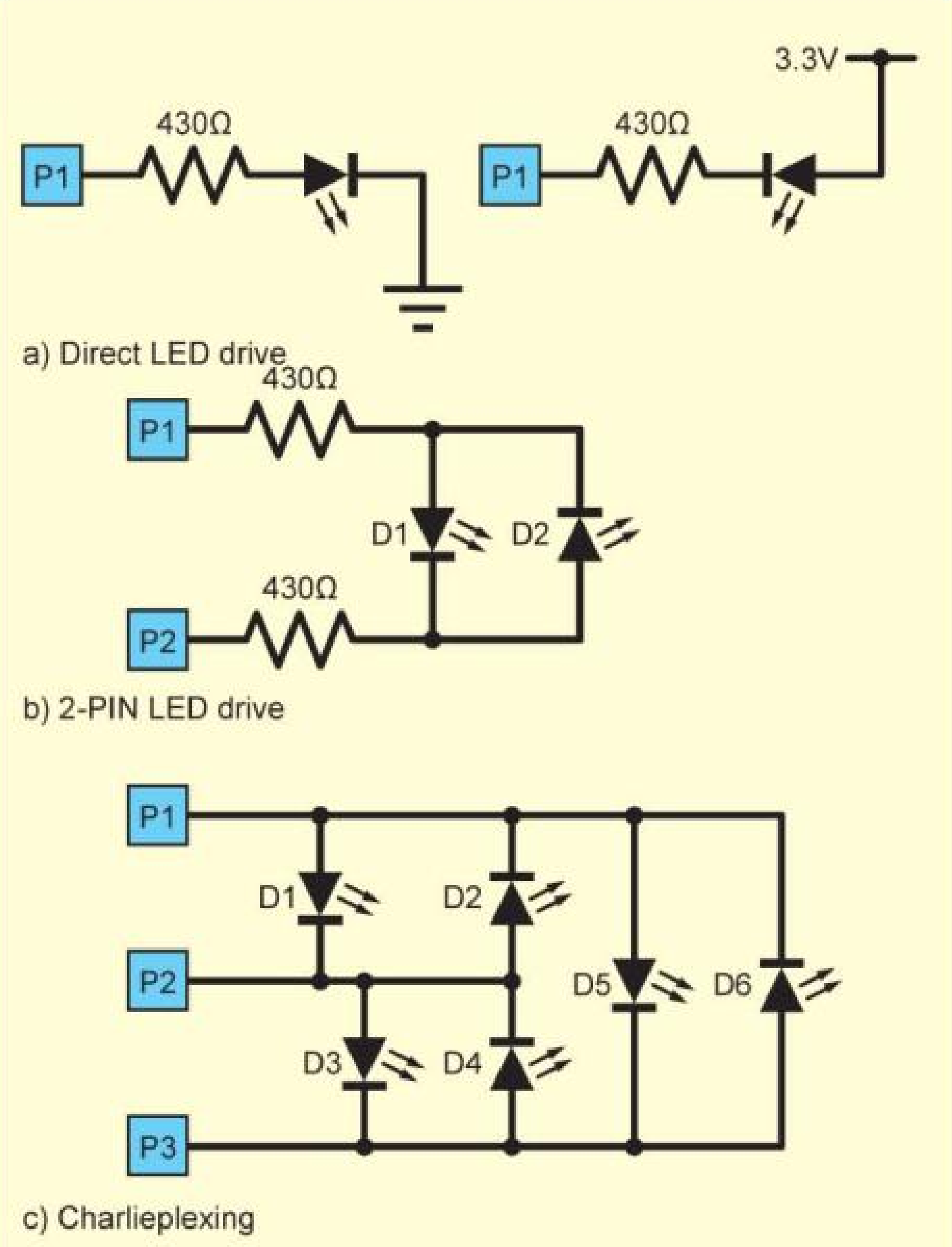
What are LEDs?

LEDs (light-emitting diodes) are small diodes, which emit light when a voltage is applied, through an effect known as 'electroluminescence'. The colour of the light is determined by the construction of the energy band gap of the semiconductor. These devices have long been popular in low-level applications such as indicators, but they are now increasingly used for general lighting applications, replacing the standard incandescent light bulbs in our homes, offices and cars. Their main advantages are ever-shrinking cost, controllability, power savings, heat reduction and relatively small size for a given brightness.

We normally activate an LED by applying a voltage across it. It really is that simple. The diode will operate once a minimum voltage (forward voltage drop) is placed across it – however, an LED has no way to regulate the current flowing through it, almost providing a direct short to ground, and without a way to limit the current flow it will quickly 'burn out' if its maximum current rating is exceeded. To control the current, we simply add a resistor in series. It doesn't really matter if the resistor is on the positive supply side (anode) or the negative supply side (cathode) of the diode, it's function is the same – see Fig.1a.

Current level and port count limits

How many diodes can I turn on using the PIC18F27J13? Looking at the datasheet for the part, PORTB, PORTC and RA6 pin can sink or source up to 25mA, whereas PORTA (except RA6), PORTD and PORTE can only sink or source 8mA. Also, the maximum current sunk or sourced from these pins is 200mA. So this means only eight of the PORTB and PORTC pins can be used to turn on any LEDs at any one time. Our standard LEDs look for about 10mA to 20mA to operate at maximum, but we can always drive these at a lower rating. Even then, we're not getting even close to driving 56 LEDs. If we look at a straight one-to-one connection arrangement, then obviously we can switch on and off 23 LEDs using our 23 GPIOs (see Fig.1a). We could connect P1 to the anode of one diode and the cathode of another diode and the other sides to P2 (Fig.1b), this would allow us to drive up to 42 LEDs (22 × 2). When P1 is high and P2 is low, then D1 lights and when P1 is low and P2 is high, then D2 lights up.



P1	P2	P3	D1	D2	D3	D4	D5	D6
0	0	0	0	0	0	P1	00	0
1	0	X	1	0	0	0	0	0
0	1	X	0	1	0	0	0	0
X	1	0	0	0	1	0	0	0
X	0	1	0	0	0	1	0	0
1	X	0	0	0	0	0	1	0
0	X	1	0	0	0	0	0	1
1	1	1	0	0	0	0	0	0

d) Charlieplexing truth table

Fig.1. Driving LEDs

Multiplexing

This is an improvement, but still falls short of our 56 target. However, there is another method known as multiplexing. This is where each pin controls a row or column of LEDs. The 4 × 4 × 4 LED cubes use this method. This allows us up to 529 LEDs (23 × 23). By asserting each pin either high or low, we can power a whole row of LEDs. However, our little PIC's current limit will not be able to drive a whole row of LEDs, so we need to steer away from that technique.

Charlieplexing

There's an interesting technique called 'Charlieplexing', which allows us – in theory – to control with N lines a total of N(N–1) LEDs (Fig.1c). So, with our 23 GPIOs, we could in theory control 506 LEDs (23 × (23–1)). That's not as much as the multiplexing method, but it is still a lot of LEDs. With Charlieplexing we turn on only one LED at any time. This method works on the principle that we can change our GPIO to an output or an input. When it's an output, we can set it high or low – basically on or off. The interesting part happens when we change our GPIO to an input. This changes the pin to a high impedance pin, effectively removing it from the circuit – neither pulling it high, nor low.

Consider Fig.1c, where we show a picture of Charlieplexing using only 3 pins. If P1 is set as a high output, P2 is set as a low output and P3 is set to an input. Then we would expect only the D1 LED to illuminate. This is true for the most part – however, there is still a voltage path through D5 and D4, and these could light up, but the forward voltage on the LEDs almost stops this from happening. Here is one of the disadvantages of Charlieplexing, it's an effect known as 'ghosting', which causes the LED to 'just' turn on.

Multiplexing versus Charlieplexing

Why use multiplexing or Charlieplexing? Charlieplexing works well when we want to limit the number of components we want to use in a circuit. With multiplexing, we would need FETs in order to drive each row or column. We would also need to use twice as many resistors and a lot more wires across the board. However, this would allow us to turn on all of the LEDs at one time. Here lies the main disadvantage of Charlieplexing – we can only turn on one LED at a time (as well as encountering the aforementioned ghosting).

The Charlieplexing software

There are a few different ways to control the LEDs. I could use look up tables and or arrays, but I'm going to keep it really simple. To start off, I create a function called LEDBLINK. In this function I want to control eight GPIOs, so I send the values of eight ports to the function. Since I want to swap between inputs and outputs, and between high and low, I use 0, 1, and 2 as a way to set each LED. 0 sets the port as a low output. 1 sets the port as a high output and 2 sets the port as a high impedance input. This gives us the three states mentioned earlier. Then we replicate this for each of our ports and that's it, we're done.

```
void LEDBLINK (unsigned int port1,
                     unsigned int port2,
                     unsigned int port3,
                     unsigned int port4,
                     unsigned int port5,
                     unsigned int port6,
                     unsigned int port7,
                     unsigned int port8) {
   /* Check each value and set LED
       * accordingly
   *  If port is 0, set low
   *  If port is 1, set high
   *  If port is 2, set as input
       * (High Impedance)
   */

   if(port1 == 0) {
        TRISCbits.TRISC4 = 0;
        LATCbits.LATC4 = 0;
   } else if (port1 == 1) {
        TRISCbits.TRISC4 = 0;
        LATCbits.LATC4 = 1;
   } else if (port1 == 2) {
        TRISCbits.TRISC4 = 1;
   }
       ...
}
```

We call our LEDBLINK function inside our main `while` loop. This sets port 1 to port 6 as high impedance inputs, sets port 7 as output high and port 8 as output low. This turns on just one of the LEDs in the matrix. Then we add a delay between each LED change and we can blink our LEDs. It would be better to place the `delayms(led_delay)` call inside the LEDBLINK function to simplify our code, as well as saving memory.

Now there are 56 different variations that we can use to control each LED individually. There's also nothing to say we can't turn on more than one LED at a time, but that would make it much more complicated. Instead, what we can do is change the delay time between switching the LEDs. We don't need to turn the LEDs on all the time, we can get away with switching them so fast that we can't tell the difference. The human eye samples the images it sees around sixty times per second, so we need to make sure we're switching faster than that. We have 56 LEDs, that we need to switch on and off more than 60 times per second, that's a frequency of 3360Hz (56 × 60). The reciprocal of this frequency (1/*f*) gives us our time delay, which is about 0.3ms (1/3360 = 2.97 × 0.0001). We need to make sure we're faster than that. In fact, our function `delayms` cannot operate this quickly, so we need a new function that will allow us to delay in microseconds instead of milliseconds. This new function is: `delayus`.

```
while(1) {
       LEDBLINK(2,2,2,2,2,2,1,0);
       delayms(led_delay);
       ...
}
```

The software is the easiest part of the project and can be downloaded from the *EPE* website.

How to build it

This is the hardest part! Starting off with the power supply, I've used a PP3 connector and a 9V battery to power the circuit. Of course other options are viable. We're looking to use around 3.3V to power our diodes and circuit since this is what our PIC is driven by. You could use two 1.5V batteries or a coin cell battery. To regulate down from 9V to 3.3V, I used an ST Microelectronics LD1117V33C, which accepts up to 15V on the input and outputs 3.3V. We'll also need a 100nF decoupling capacitor between the input and ground, as well as a 10µF capacitor between the output and ground. Ceramic capacitors should suffice for both of these. See Fig.2 for a diagram of how these are connected.

Components list

1 off	LD1117V33C (IC1)
1 off	100nF capacitor (C1)
1 off	10µF capacitor (C2)
2 off	100Ω resistors (R1, R2)
1 off	9V Battery
1 off	PP3 connector
2 off	Yellow LEDs
2 off	Red LEDs
4 off	Green LEDs
2 off	AC LEDs (MCL236PURGW)
32 off	Dual LEDs (MCL239YGW/MCL239AGW/ MCL239PURGW)
1 off	Veroboard (26 holes across and 26 holes down)

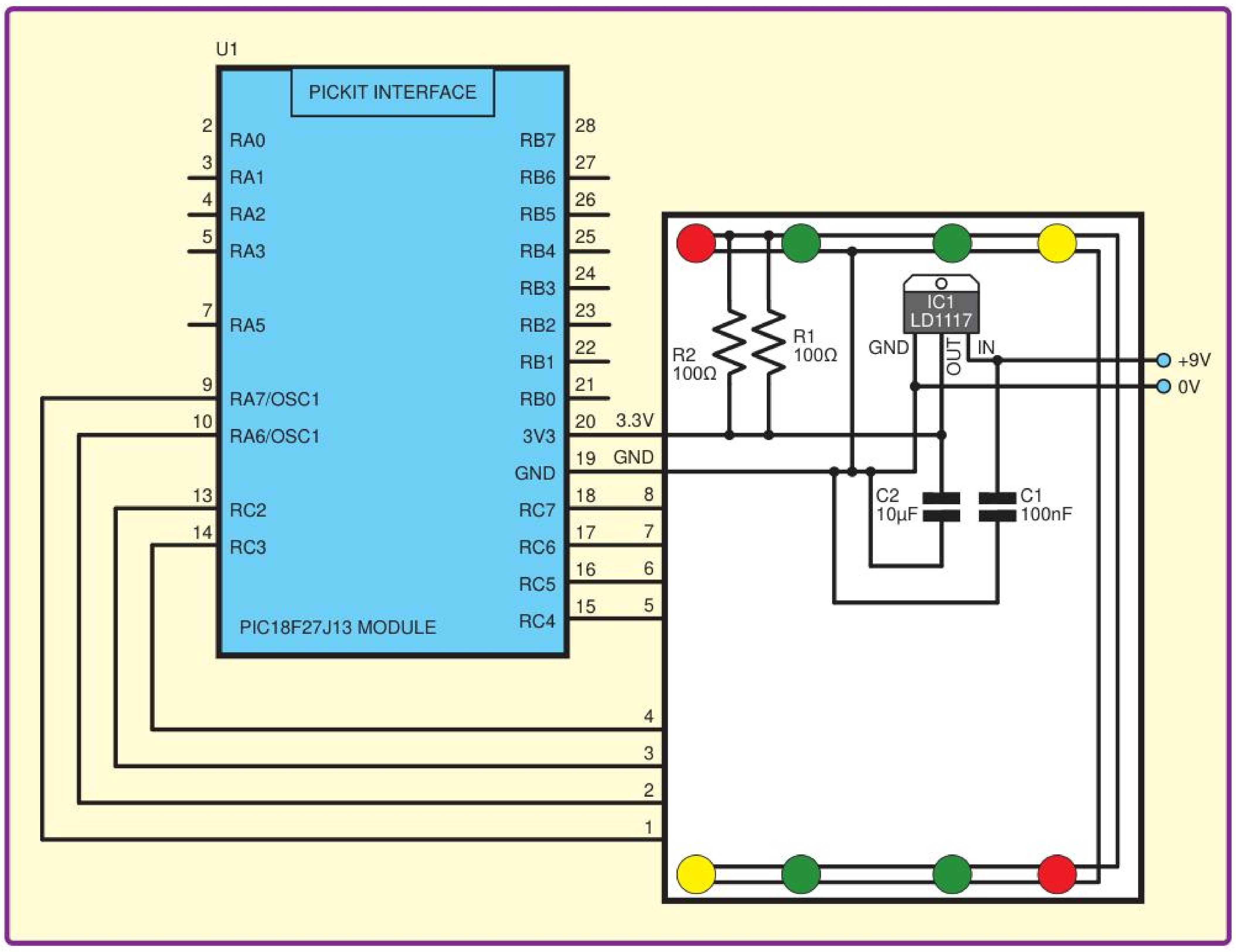


Fig.2. PIC-to-LED board

Power supply considerations

I've added the power supply connectors and wires to our breadboard as seen in the Fig.2. To make it sit up off the table, I could have used screws or standoffs, but I figured it looks better with LEDs and they are a handy power indicator. I've attached two red LEDs and two yellow LEDs as standoffs at the bottom of my breadboard as well as four green LEDs above. These are all standard, off-the-shelf, round 5mm LEDs and two 100Ω series resistors (in parallel) for current limiting. Note that in keeping with the project's philosophy of minimising components I have paralleled each set of four LEDs, both running off the two paralleled current-limiting resistors so effectively all eight LEDs are in parallel). This does mean I cannot control the individual currents through each LED, so there will likely be some variation in brightness – typically a red or yellow LED has a lower forward voltage drop than a green (or blue) LED, and will end up being a little brighter.

Building the tree

For the tree, Multicomp have a series of three-legged dual LEDs with the common cathode in the centre. They come in YELLOW/GREEN, ORANGE/GREEN and in RED/GREEN combinations (MLC239 range). These are a great way to reduce the number of wires and components in total. It's also very easy to vertically stack them on top of each other. See Fig.3 for our stacking arrangement. We have four stacked three high, eight stacked two high and four on their own. As the build process is a little complicated, I've itemised the instructions below.

1) In order to stack them in this arrangement, the two outer pins of each diode are soldered to the two outer pins of the diodes below.
2) The centre pins of the bottom diodes are soldered into the Veroboard.
3) The centre pin of the second diode up is bent at a right angle towards the centre of the tree and we add a wire connection to its associated wire number.
4) The centre pin of the third diode up is bent at a right angle again towards the centre of the tree and we add a wire connection to its associated wire number.

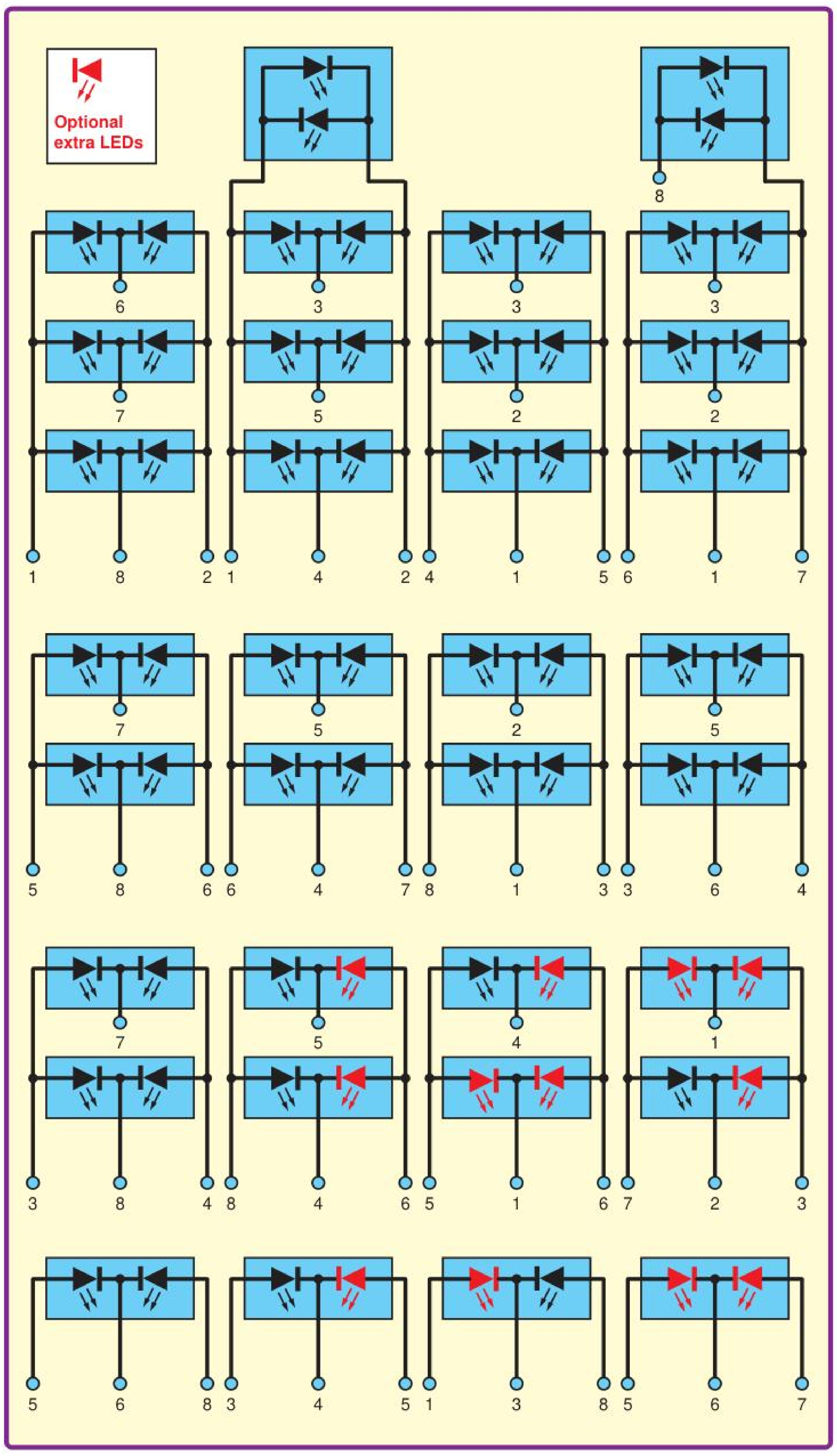


Fig.3. LED wiring diagram

I've designed the easiest way to wire up the Veroboard, with the minimum wiring. Fig.4 shows all of our cutting and wiring. Numbering the instructions again, we get:

1) See Fig.4 for where to cut the Veroboard. Each red line represents a cut in the Verboard copper tracks. This isolates each connection. You should use a sharp craft knife to carefully cut the copper track.
2) Fig.4 also shows our wiring. Now this looks like a proper rats nest and it will take some time and care to get it all working. I have made it easier by colour coding the wiring connections and you should definitely add the alphanumeric coordinates to your board to help you navigate the 676 holes on the board! We can add an eight-row header to our board in the black outlined area. This is numbered for each specific colour (excluding the larger outer LEDs). This header allows us to connect up our PIC to control our LEDs.
3) For the wiring, start with pin number 1, which is grey. Add all of the wires on the copper side of the board. You will need to solder wire on the copper side of the board, so where it crosses tracks ensure you use insulated wire. Then move through each number following the wiring in the diagram. This will ensure nothing is missed.
4) Fig.4 also shows the top (component) side of our Veroboard, where you need to add just the eight wires shown.
5) Next add the LD1117 regulator. Note that pin 1 (left most) is ground. The centre pin is our 3.3V output. Pin 3 is our 9V input (right most). You can see the connection of the 100nF capacitor between ground and 9V, and the 10µF capacitor between 3.3V and ground.
6) Add the two Red LEDs and two yellow LEDs on the bottom side of the board in each corner. Add the four Green LEDs to the top of the Veroboard as shown. Don't forget the anode pin of the diode (positive and longest leg of diode) must be connected to the positive rail. I've added a plus sign on each of these LEDs to help make this easier. Add the two 100Ω paralleled current-limiting resistors as seen in the diagram. Once we apply power, these eight LEDs should all power on.

Now that we've wired up the Veroboard, it's time to build our tree.

Note that in Fig.4, I've stacked up the diodes three high for the four *centre columns*, the *next outer row* is two high, the *last outer row* is one single dual LED. Also notice that the centre pin on the columns may be different as well. Match the numbers at the bottom of each column to the mapping in Fig.4, which shows the pin mapping for the easiest Veroboard mapping.

Taking a look at both Fig.3 and Fig.4, we need to start pairing up our numbers and see where everything goes. Starting with *centre columns*, the three-stacked assembly, we start with our first column numbered 1,8,2. In our colour coding, this equates to grey, dark green and lilac (light purple). Looking at Fig.4, we can see this is on the right hand side (the LD1117

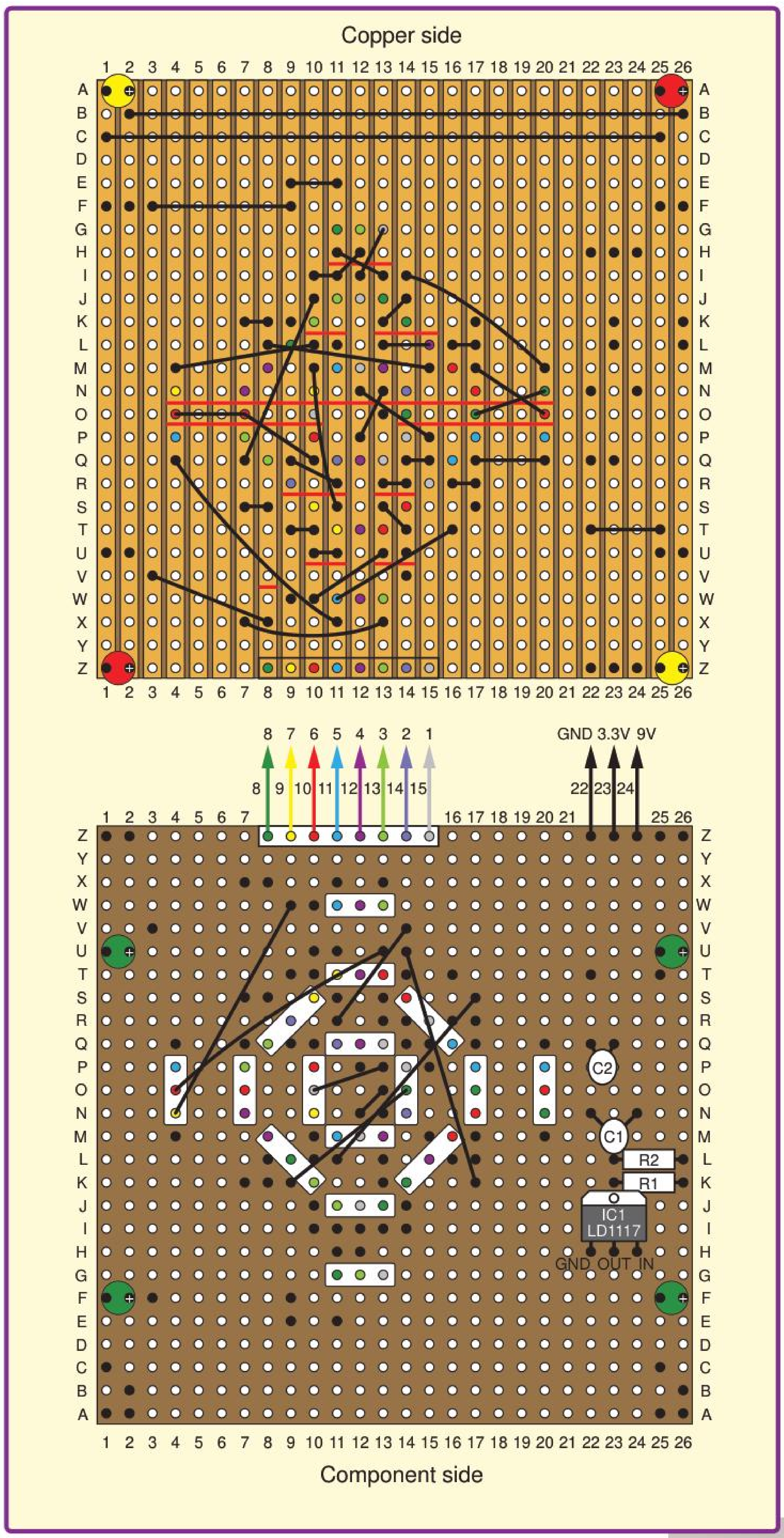


Fig.4. Veroboard mapping – not the easiest diagram to follow! We recommend you download a high resolution PDF of this image form the EPE *website*

side). We place the diode through the Veroboard and solder on the bottom side. The centre pins for the second and third diodes up still need to be connected. We can do this by adding a wire to these and connecting them through our Veroboard to connection 7 (yellow) for the second tier and connection 6 (red) for the third tier.

Our next three-stack is 1,4,2, which is grey, purple, lilac. Looking at Fig.4, this is just to the left of our first set of diodes. Continuing around like this, we can add all of our paired LEDs and build up our tree. Just a last note on this, there are four sets of two stacked high diodes, which are placed diagonally on the board. These are wired up in the same way.

As a little extra, the final two LED pairs at the top of the *centre columns* are Multicomp's 2-pin dual LEDs. These LEDs are wired with two diodes in parallel and in opposite directions to each other. If a high is seen on one side, one colour is visible, when a high is seen on the other side, a different colour is seen. See the two LEDs at the top in Fig.3.

Once we've completed the *centre columns*, we can move onto our *next outer row* and the *last outer row*.

You may have noticed that in Fig.3 we actually have 68 diodes in total. When building the tree I found using only the 56 LEDs leaves the tree unbalanced. These optional 12 diodes are not completely necessary and can be left unconnected. If used, they will be lit at the same time as other diodes, but I found these make the tree more aesthetically pleasing. I've highlighted the 12 extra diodes in red on Fig.3.

Last, but not least, connect up the GPIO pins to the LED Veroboard as shown in Fig.2. The Veroboard connection numbering (1-8) is matched to the LED pin numbering in Fig.3.

Once, we've connected up all the LEDs and wired up our *LPLC* board to our *LED PICmas* Veroboard, we can program it and have our little festive light show.

Future improvements

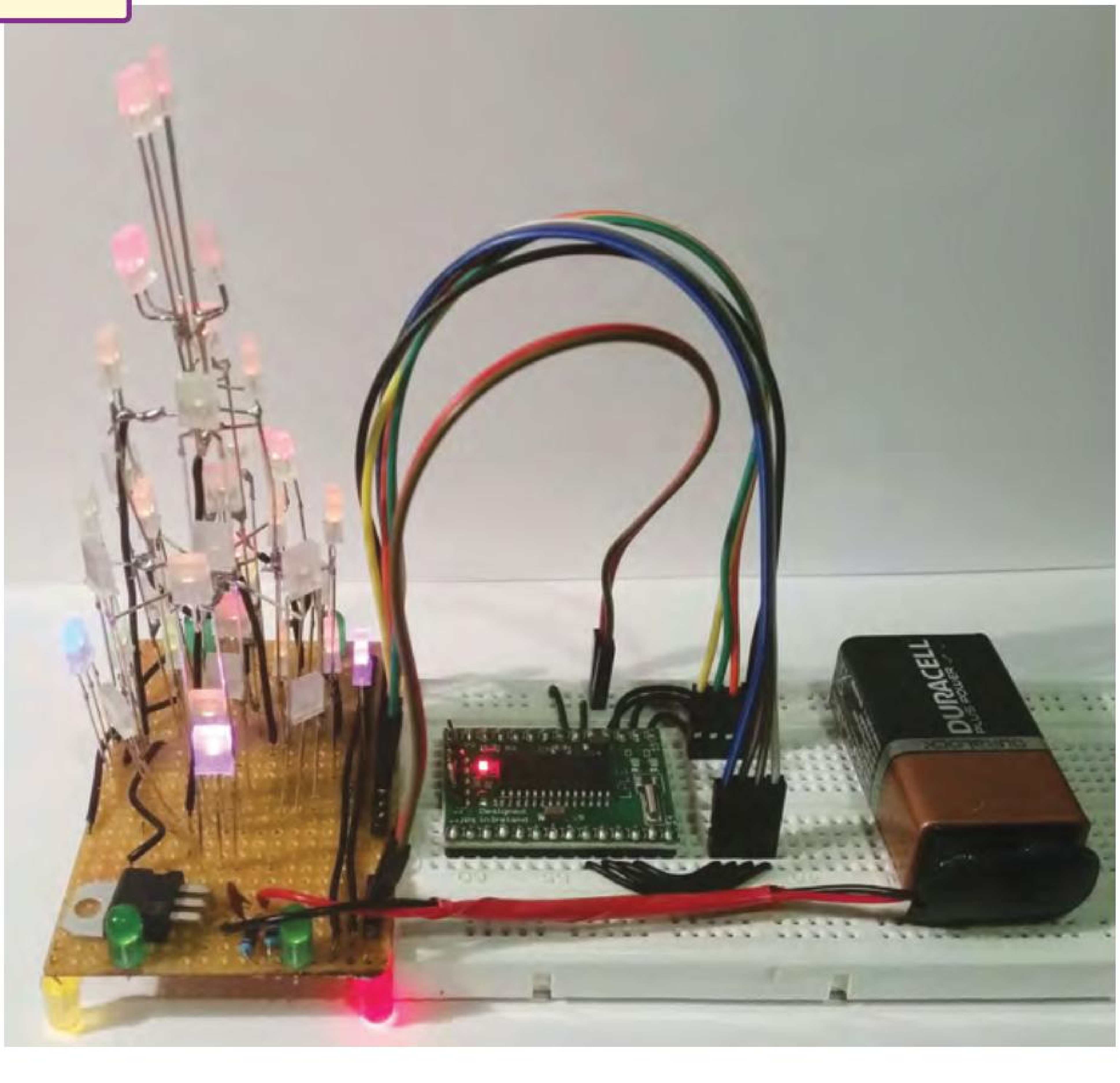
I like to finish off any little project with ideas about what I could do better and faster. I like the method of Charlieplexing; it allows me to control lots of LEDs with minimal components. Since we have a lot more GPIOs on our PIC, I'd like to have used a lot more LEDs and 'gone much larger'. It would also be better to spread out the LEDs better. Also, as we've seen above, the wiring is a nightmare. It wouldn't take much to design a small little PCB for this, which would make our little tree look a lot more professional and easier to build.

Next month

Next month, I'm going to take a look at managing software development with open source tools. This will include looking at various software development packages and repositories like; Git, GitHub, BitBucket, Google Code, as well as bug trackers like Trac, JIRA and BugZilla. Until next time, Happy Christmas and a Happy New Year.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

Fig.5. Finished PICmas Tree



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MARCONI 2955B Radio
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Pendulum CNT90	Timer Counter Analyser 20GHZ	£750
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Solartron 7150	6 1/2 Digit DMM True RMS IEEE	£65
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Solatron 7075	DMM 7 1/2 Digit	£60
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
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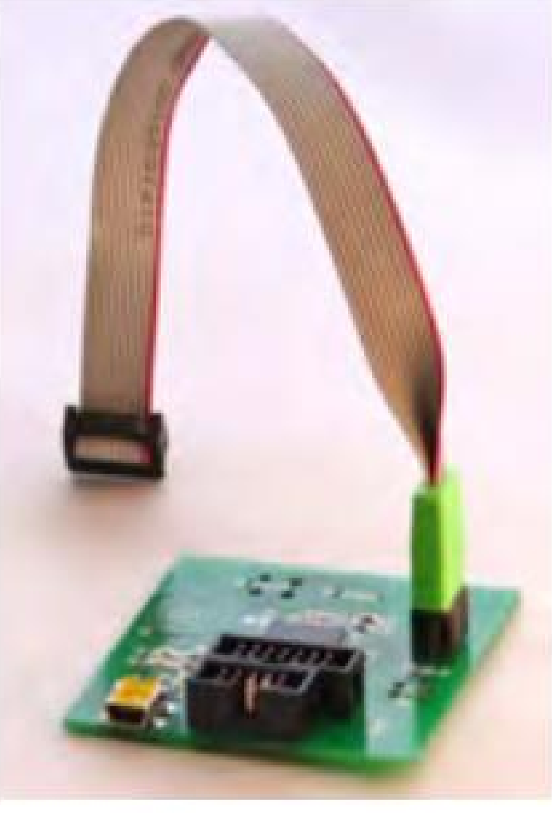

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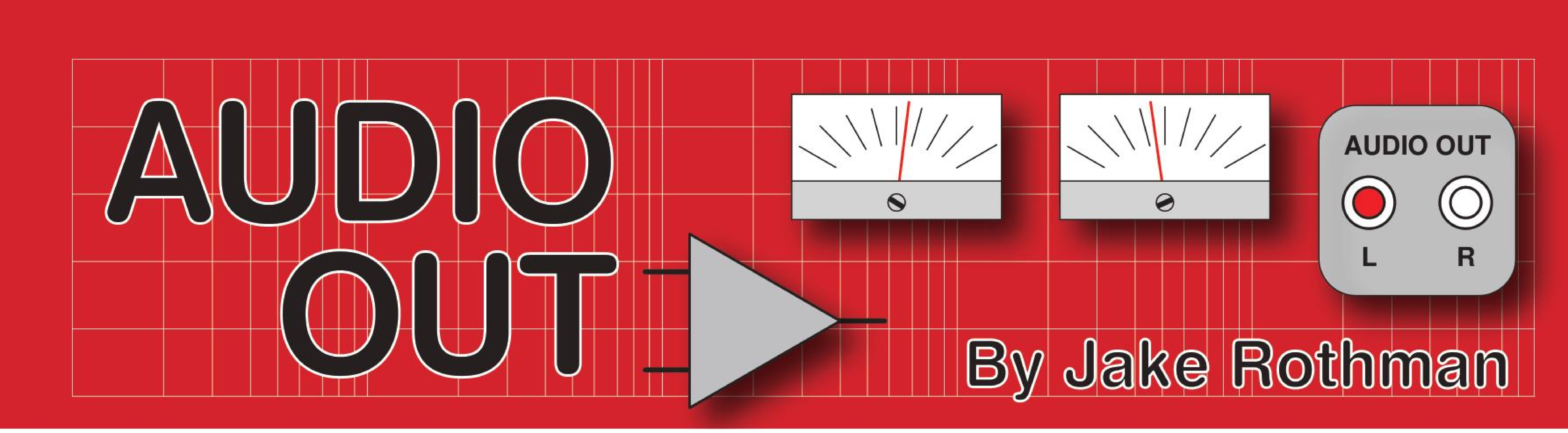


AUDIO OUT

By Jake Rothman

Audio filter building block

We take a one-month detour from volume controls this month and deal with another common audio building block, the filter. Filters are widely used in audio/music systems – tone controls, rumble filters, bass boosters, multi-way loudspeakers and synthesisers; the list is long.

The purpose of this article is to enable a filter-design beginner to make their own audio building block using the popular Sallen-Key active design. Although many other design options are available – some of which will be covered in future articles – the Sallen-Key is a good, tried-and-tested place to start. I am providing a simple PCB design for readers to use (download from the *EPE* website) and constructed examples are shown throughout.

Passive filters, high-pass / low-pass

Before we get into the nuts and bolts of active filters it is worth remembering that there are plenty of useful passive designs, by which I mean they require no power source and simply provide frequency-dependent attenuation. An example is a two-way loudspeaker passive crossover filter, which splits the frequency range between the woofer and tweeter. In the cheapest systems, this is just a capacitor feeding the tweeter to filter out the bass (Fig.1) – it's the simplest form of high-pass filter. In standard 8Ω systems, this is normally a 2.2µF to 4.7µF capacitor. In slightly more expensive units, an inductor will be used to filter any treble going into the bass unit, as shown in Fig.2 – this inductor acts as a low-pass filter.

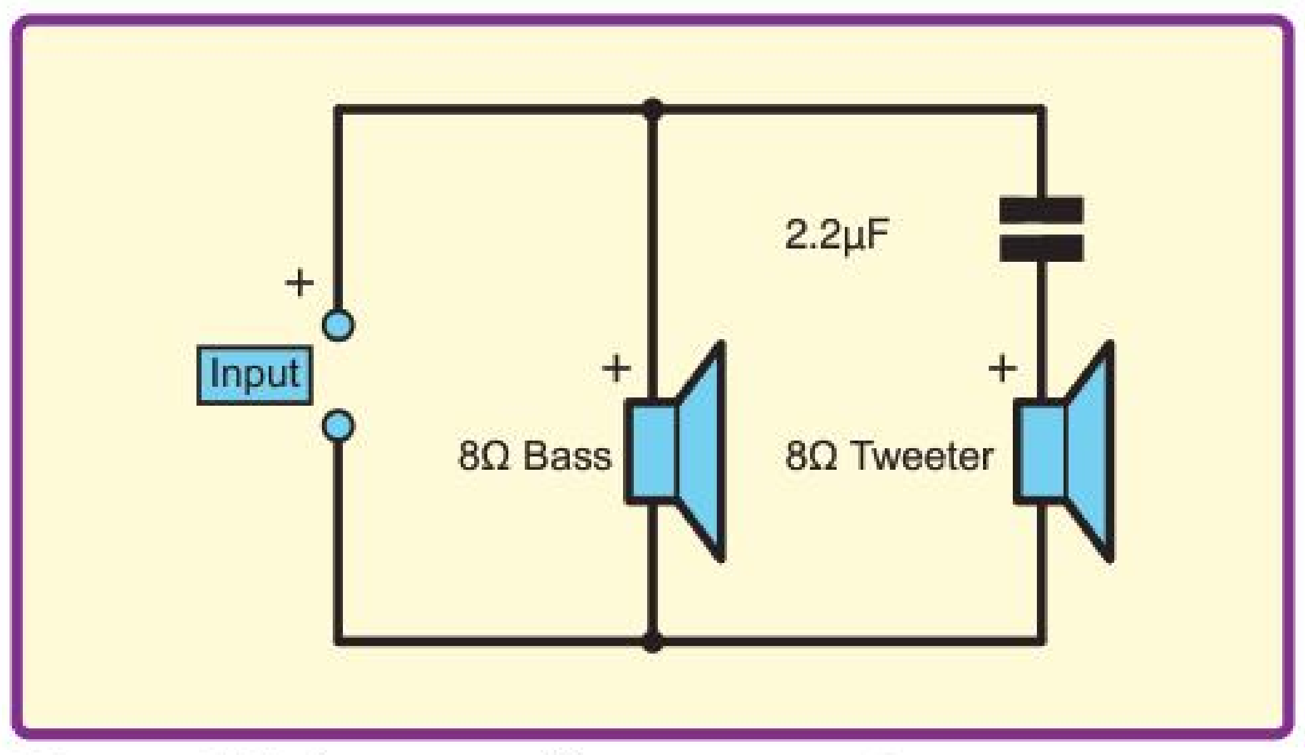


Fig.1. High-pass filter capacitor to protect tweeter, possibly the simplest audio filter

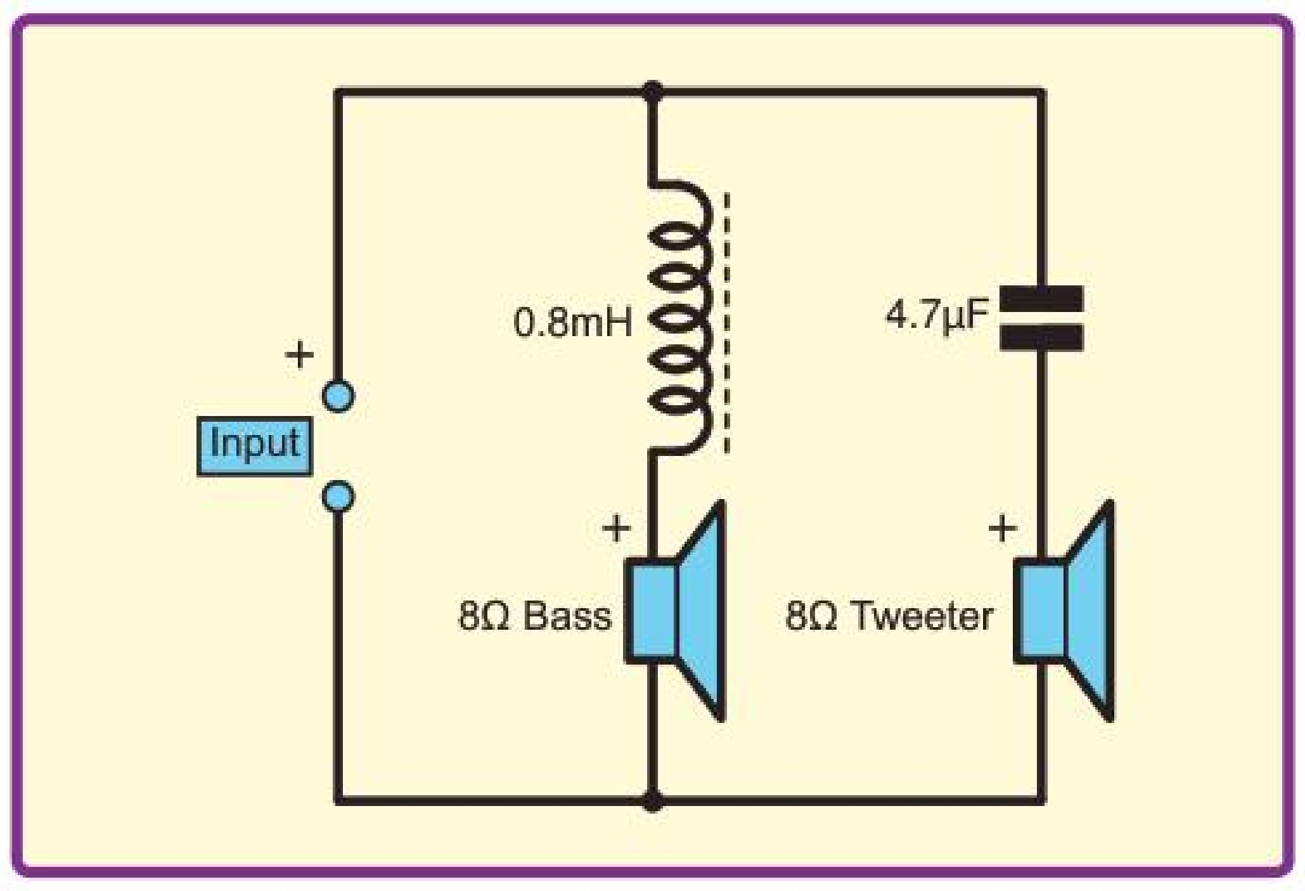


Fig.2. Passive inductor to provide low-pass filtering for bass unit

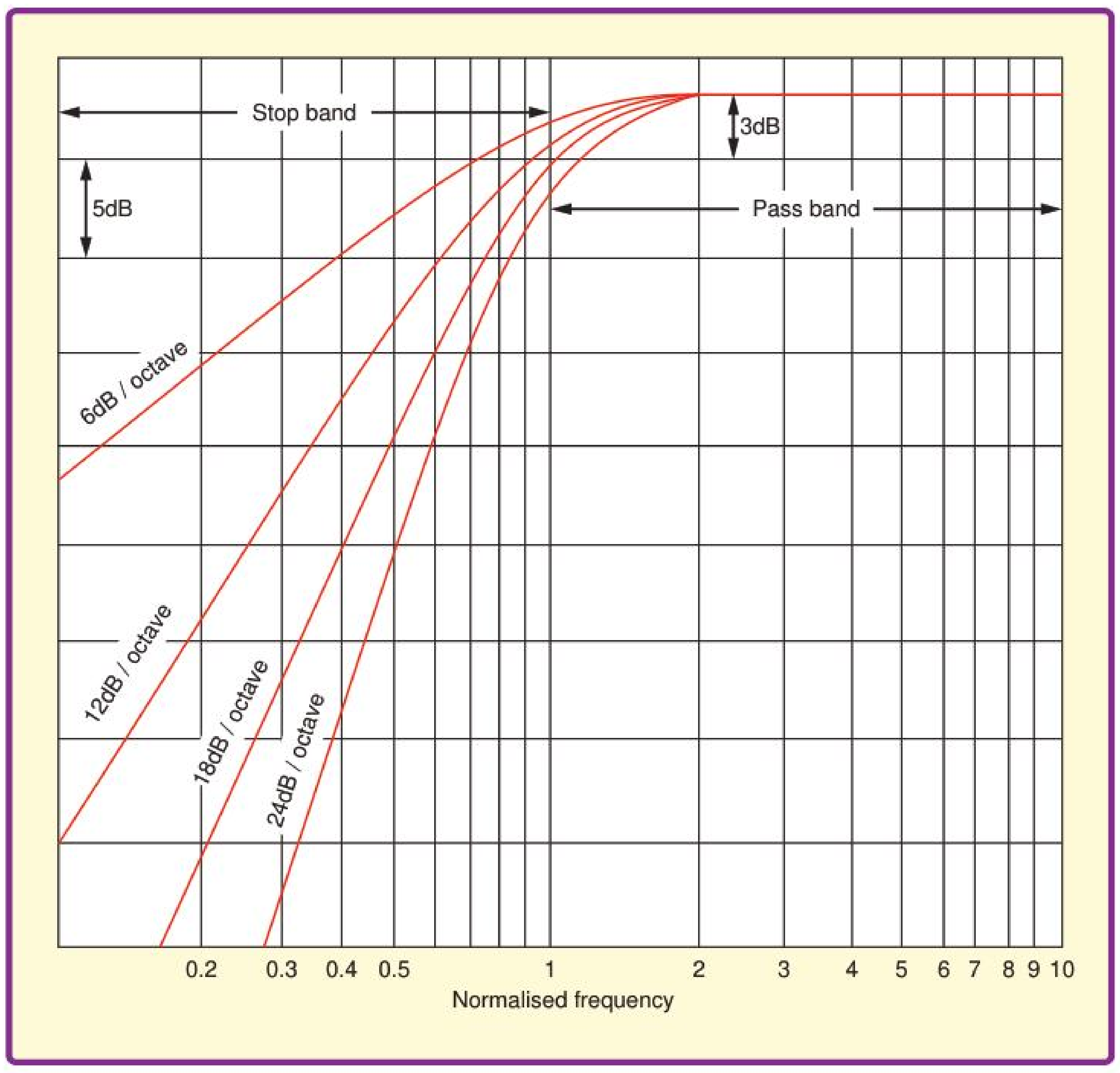


Fig.3. Graph showing different slopes of first- to fourth-order high-pass filters – the corner frequency is taken to be –3dB

Filter order

Filters with a single coil or capacitor will roll-off at 6dB per an octave, with the level halving for a doubling of the frequency. Such filters are called 'first-order', from their mathematical characteristic. (Generally speaking, for active or passive filters, the number of reactive components – capacitors or inductors – in the filter gives you its 'order'.) Fig.3. Shows the effect of increasing the order from first to fourth. Essentially, the higher the order the greater the attenuation with frequency.

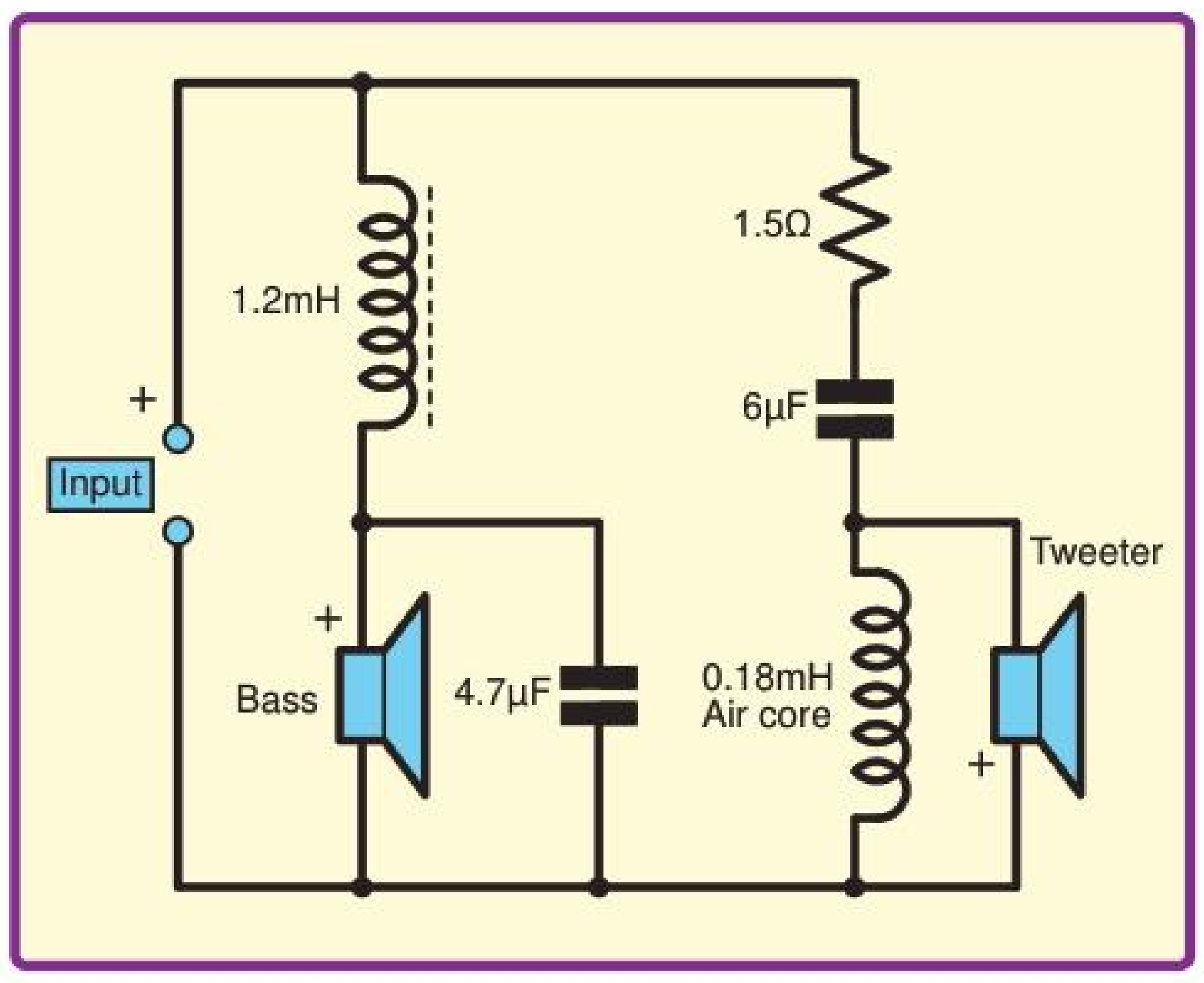


Fig.4. Second-order passive crossover in Celestion DL4 loudspeaker system

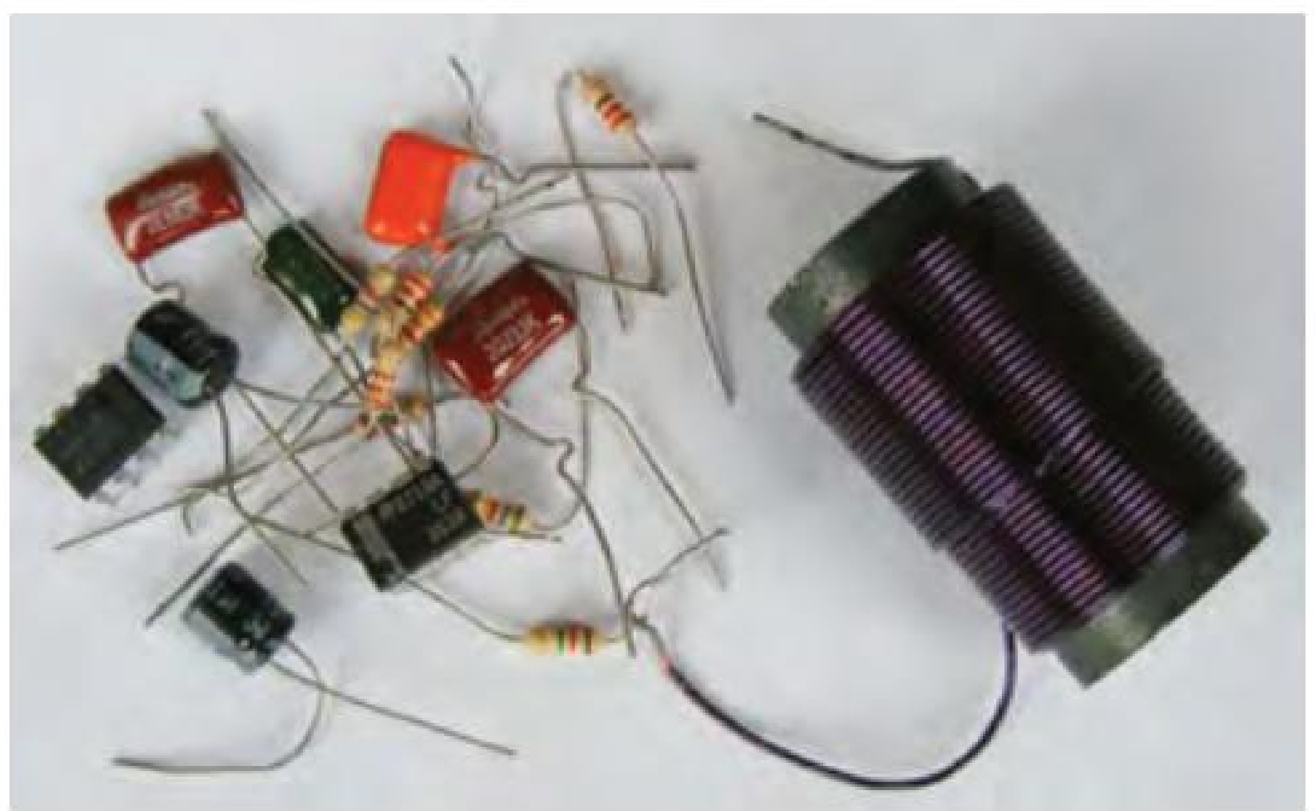


Fig.5. Contrast between passive inductor used in loudspeakers and parts to make an active filter crossover

In a further elaboration (Fig.4) an additional capacitor and inductor will be used, giving a 12dB/oct or second-order roll-off. Most consumer speakers don't go beyond this order, but some BBC monitor and KEF speakers used third or even fourth-order filter networks. A more complex crossover allows a flatter frequency response to be obtained.

Cut-off frequency

The 'cut-off' or 'corner' frequency of an audio filter is normally taken to be the point at which the level has dropped by 3dB, equivalent to falling to 0.707 of its input value. If it is necessary to have no significant

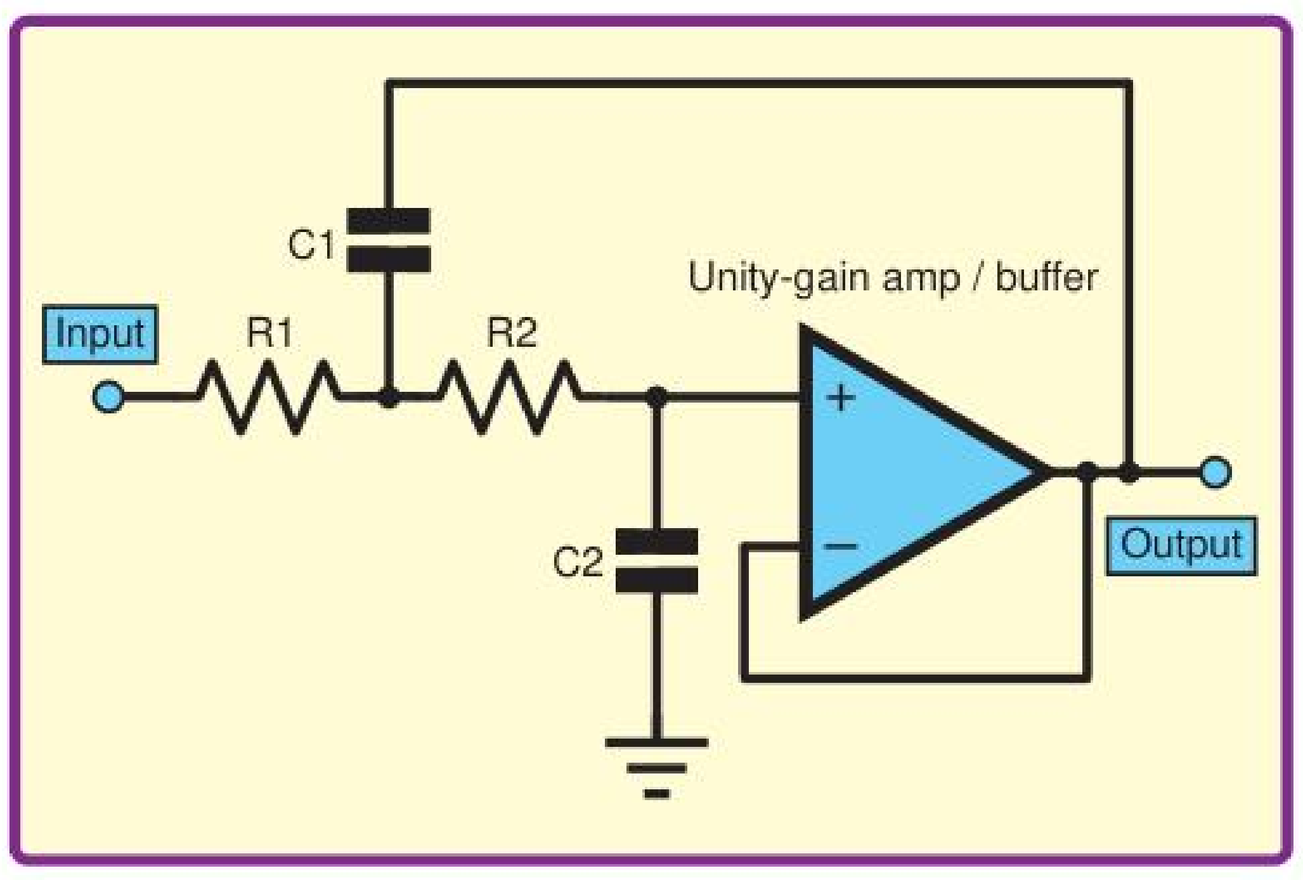


Fig.6. Low-pass Sallen-Key – the ratio between capacitors sets the damping, which determines the type of filter (Bessel, Butterworth or Chebyshev). Resistors are usually equal value

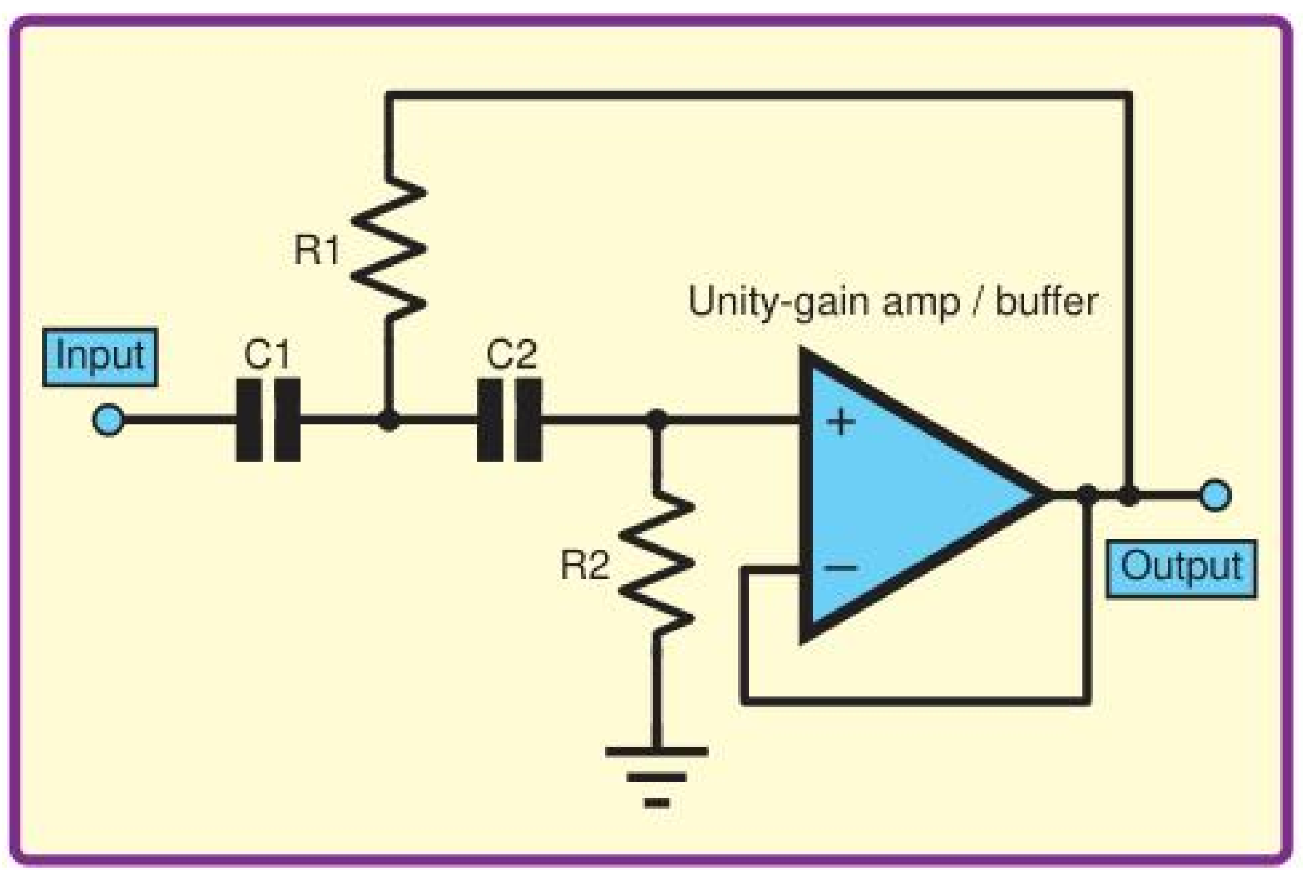


Fig.7. High-pass Sallen-Key – the ratio between the resistors set the damping, which determines the type of filter. Capacitors are normally equal value

attenuation at a particular frequency it is necessary to move the corner frequency beyond the frequency in question. If we take the maximum acceptable attenuation to be 1dB, this would equate to around 700Hz for a 1kHz-corner-frequency low-pass filter or 1.4kHz in the case of a 1kHz-corner-frequency high-pass filter.

Active filters

There are two major problems with passive filters; first, the cost of inductors. Large lumps of ferrite wound with copper wire are expensive. It was trying to avoid inductors for filters below 30Hz that inspired RP Sallen and EL Key's seminal filter design paper in March 1955 (available from the IEE). (Of course, their circuit originally used valve cathode followers – not the easier-to-use op amps we employ today.) At current prices, one loudspeaker crossover inductor costs around £3, which would buy you several chips and a handful of small resistors and capacitors, illustrated in Fig.5. A more serious problem with magnetic-cored inductors is distortion from hysteresis and saturation. This is where the active filter really scores – it needs no inductors, just resistors and capacitors. Making a filter in this way would normally be very lossy, but the low-cost gain available with active devices, such as transistors and especially op amps, can compensate for this with the judicious use of positive feedback. The distortion is also normally an order of magnitude below that of inductor-based filters.

Sallen-Key

The classic active filter circuit, the Sallen-Key topology, used a unity-gain amplifier or buffer stage with a passive RC network, plus another RC network fed from the output to provide a bit of positive feedback. This design can provide low-pass and high-pass filters – shown, respectively in Fig.6 and 7.

Classic curves

Sallen-Key filters are usually designed to work with three different classes of filters based on different mathematical designs that prioritise flatness of response or phase preservation, or a balance between the two. They are called: 'Bessel', 'Butterworth' and 'Chebyshev'.The Bessel is less effective as a filter, having a less sharp function, but it has no overshoot or ringing. The Chebyshev, which has the fastest roll-off, is usually designed to have ripple of ±1dB or ±3dB in the passband. These two filters are rarely used in audio work and we won't cover them in this article. That leaves the Butterworth, which is normally used in audio designs since it has the flattest passband, while still providing rapid roll-off. This is especially important to provide protection for tweeters. All the subsequent designs in this article are strictly Butterworth. (Bessel and Chebyshev are excellent filter topologies, and definitely have their place in electronics – just not in audio.)

Equal-component design

From a design point of view, the easiest type of Sallen-Key filter is the 'equal-component' or 'voltage-controlled voltage-source' filter, thankfully abbreviated to the VCVS filter. This is easy to design since both pairs of capacitors are equal, as are the resistors. The unity-gain buffer of the original Sallen-Key is replaced with an amplifier with modest gain.

The equal-component Sallen-Key is shown in Fig.8. We have two sets of calculations to make. We need to determine the filtering resistors (R1 and R2) and capacitors (C1 and C2), and we need to calculate the non-inverting op amp gain (set by R3 and R4).

Before we go any further, a note about values for R1 and R2. In theory, the algebra will let us use any value of resistance, but in practice values should be restricted to between 4.7kΩ and 100kΩ. A safe value for audio work is typically around10kΩ. Much lower than this, and distortion increases due to loading. The popular TL071 op amp starts distorting badly when feeding loads below around 3kΩ. (However, the 5532 op amp (an audio favourite) can drive 600Ω.) Above 10kΩ, Johnson noise starts to become significant and increases with resistance. Many text books suggest 100kΩ, which keeps the capacitor values low for cost saving. But, 100kΩ is a bit 'hissy' for good quality work, and since capacitors have got smaller and cheaper we'll stick with 10kΩ.

Designing an equal-value, low-pass second-order Butterworth filter

Now, after all that waffle let's design our first filter! All we need to do is follow four easy steps.

Step 1 – definition

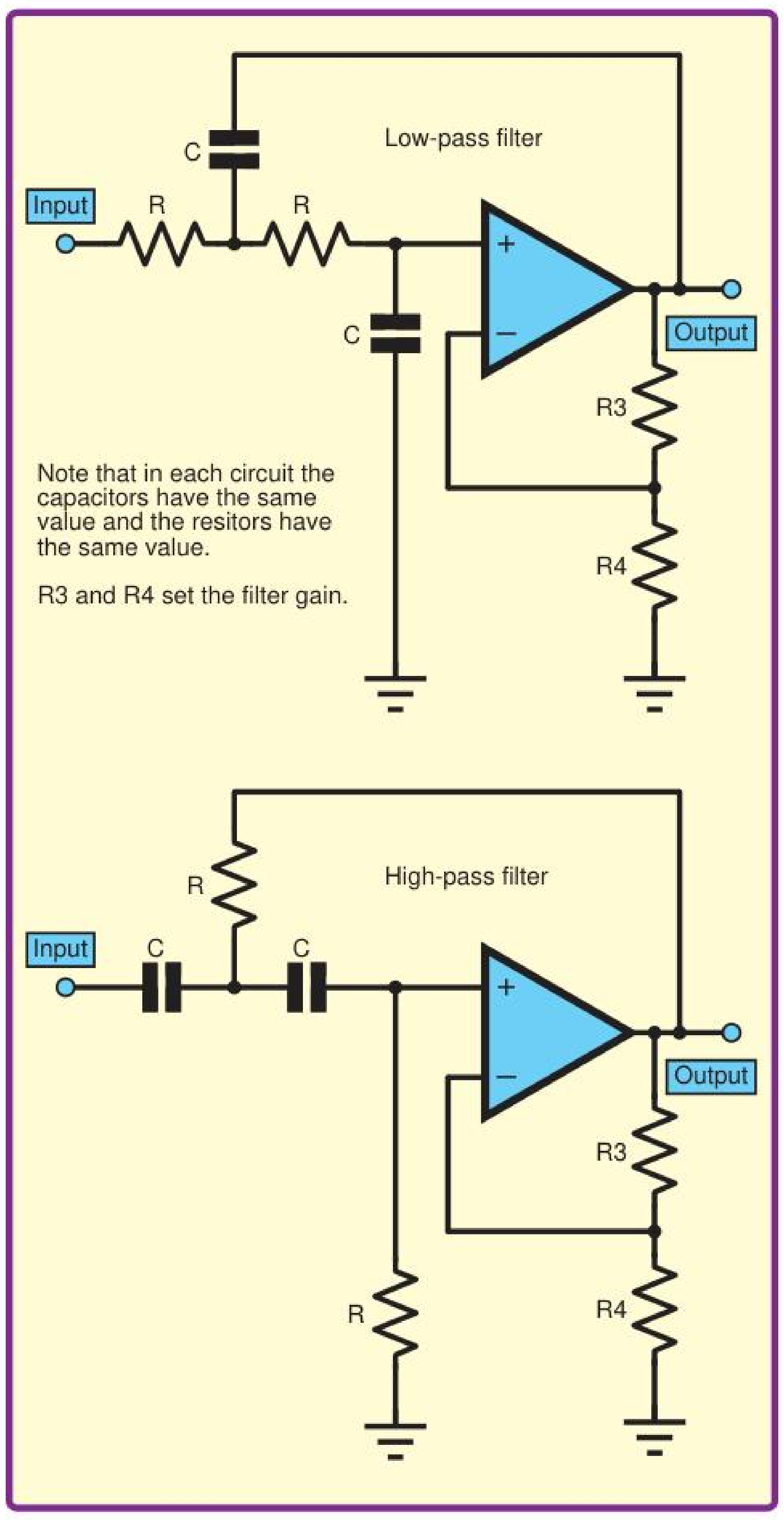
Let's assume we want a low-pass, second-order Butterworth filter with a corner frequency of 1kHz. Remember that since this is an equal-value filter we can say the R1 = R2 = R and C1 = C2 = C.

Step 2 – choose R, the filter resistors

We'll start off with the 10kΩ recommended above. If this produces unwieldy capacitor values (see Step 3) then we can always change this choice, but in the audio range of frequencies it is likely to be a pretty safe choice. So, R1 = R2 = R = 10kΩ

Step 3 – calculate capacitor C values

The corner frequency f_c, filter resistor R and capacitor C values are simply



Note that in each circuit the capacitors have the same value and the resitors have the same value.

R3 and R4 set the filter gain.

Fig.8. Equal-component Sallen-Key filters

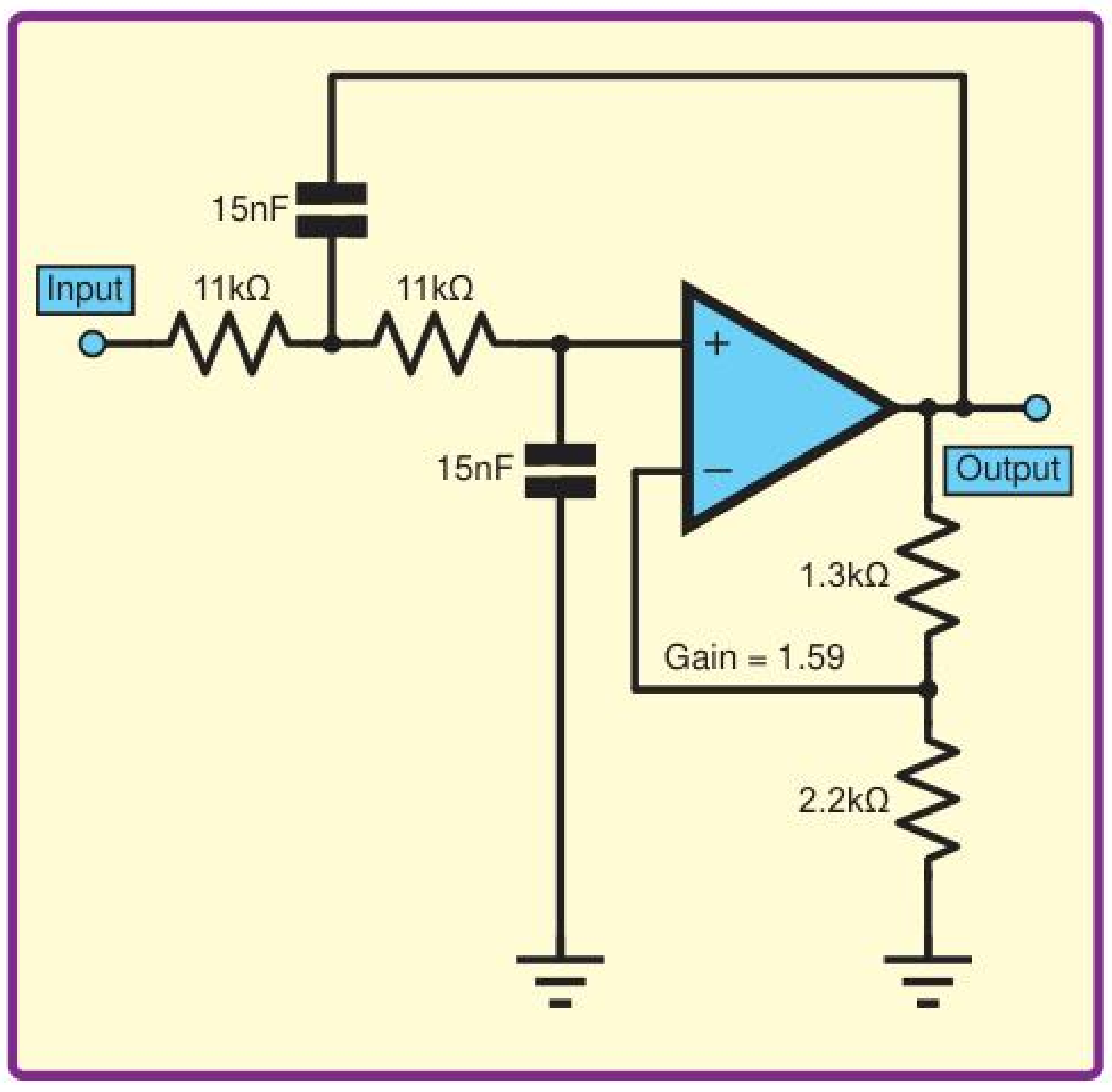


Fig.9. 1kHz Butterworth equal-component low-pass filter

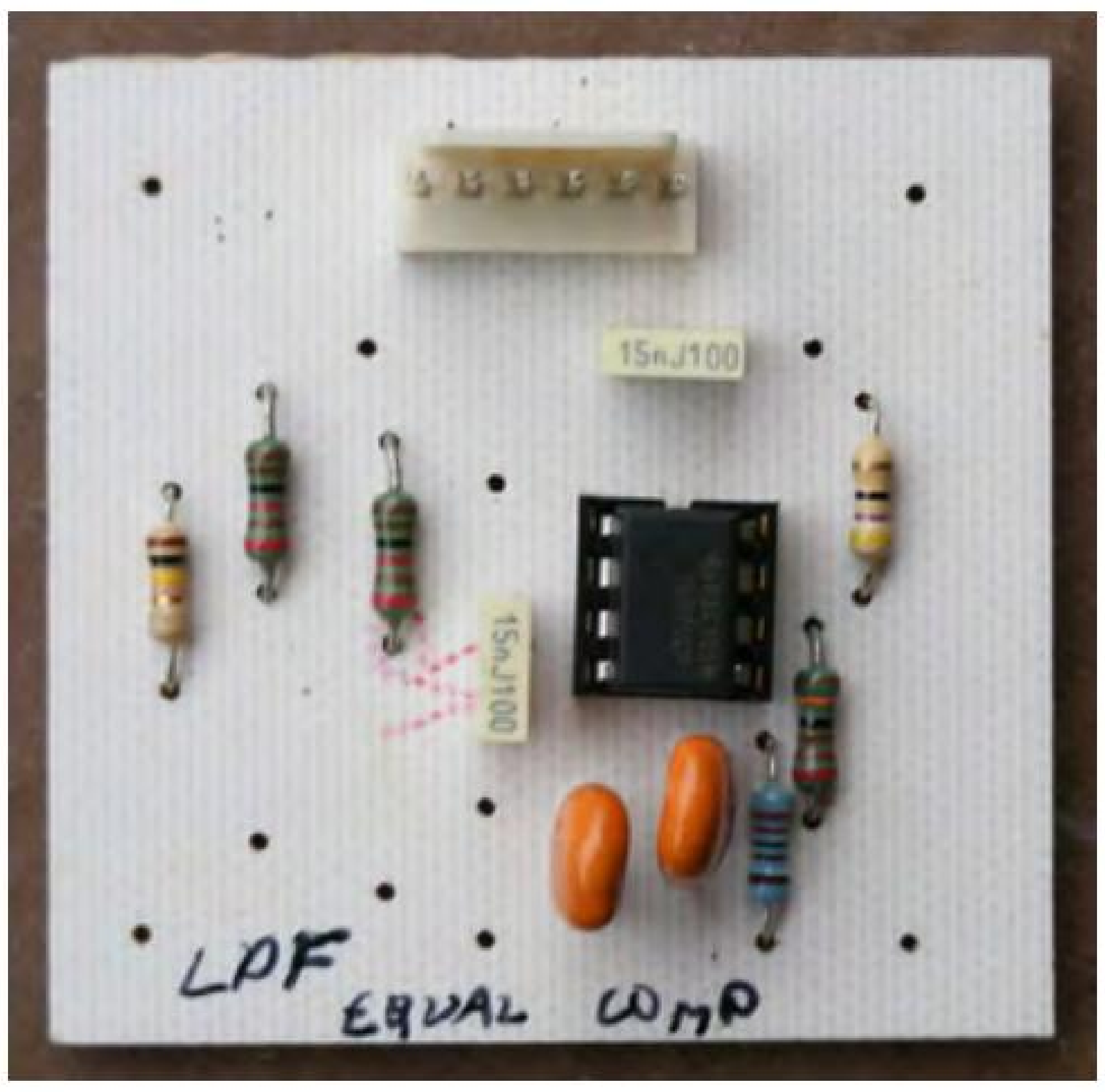


Fig.10. Assembled PCB for Butterworth equal component low-pass filter

related with the following easy-to-use equation:

$$f_c = 1/(2\pi RC)$$

This is easily manipulated to give values for C as follows:

$$C = 1/(2\pi f_c R)$$

To calculate our capacitor value we just drop in our values for R and f_c thus:

$C = 1/(2 \times 3.14 \times 1000 \times 10000) = 5.9 \times 10^{-9}$F
This is 15.9nF, and the nearest E12 available value is 15nF.

Step 4 – set the gain of the op amp

We said that the op amp has 'modest' gain, but how modest? The actual calculations can be a little involved, so you will have to take my word for it when I say the gain for all second-order, equal-value Butterworth filters should be 1.586 – or as near as possible given available resistor values. This is a standard non-inverting op amp, so the gain, k is set by:

$$k = 1.586 = 1 + R3/R4$$

Let's make R4 = 2.2kΩ (to avoid loading) and find the correct value for R3. Rearranging to find R3 we have:

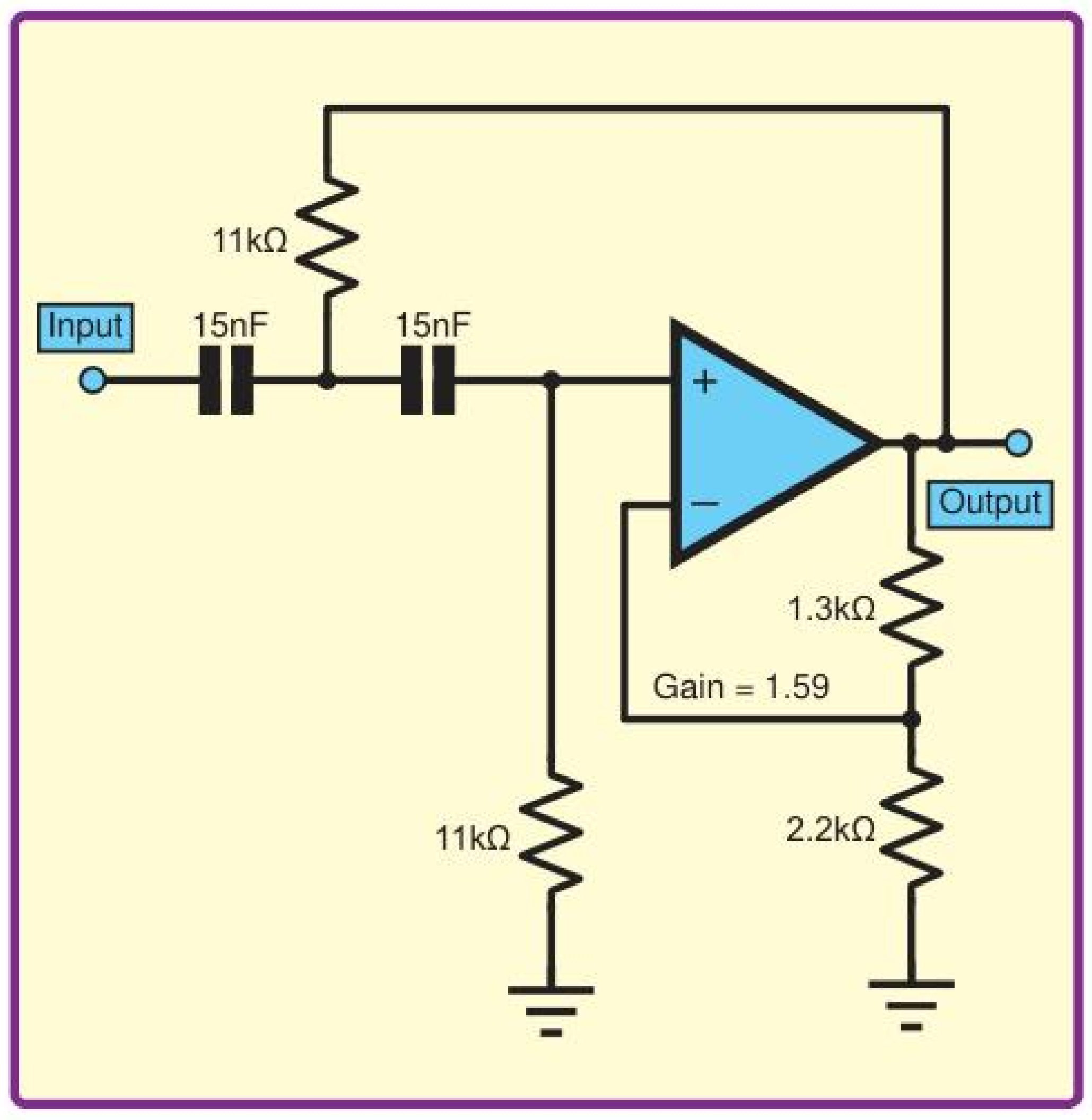


Fig.11. 1kHz Butterworth equal-component high-pass filter

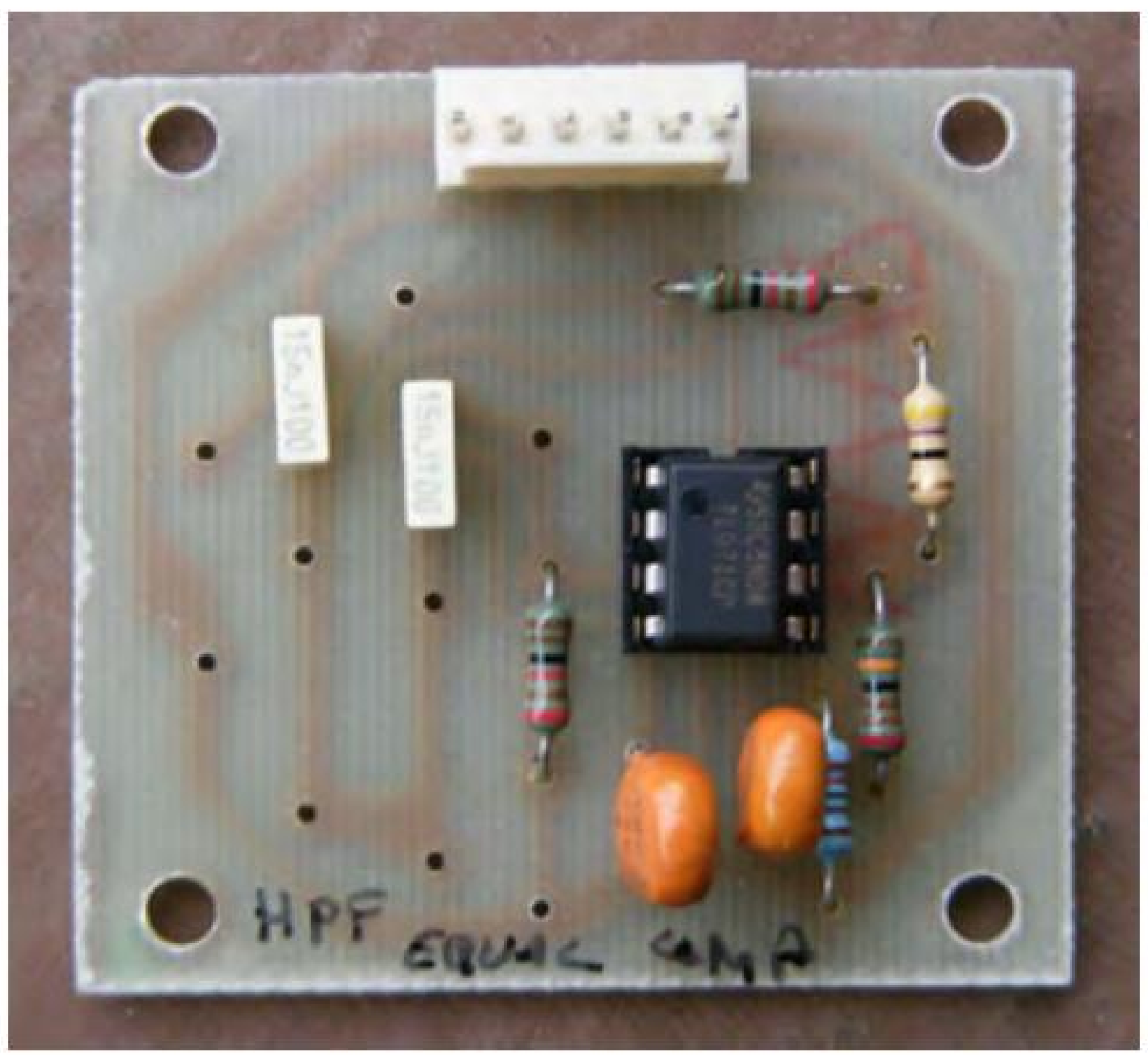


Fig.12. Assembled PCB for equal-component, high-pass filter. Note the board takes standard 5mm box polyester capacitors if needed

$R3 = (k - 1) \times R4 = (1.586 - 1) \times 2200 = 1289\Omega$
The nearest preferred value is 1.3kΩ, which gives us a gain of 1.591, which is very close to our target of 1.586.

Designing an equal-value, high-pass second-order Butterworth filter

Now let's try our hand at designing a high-pass filter.

Step 1 – definition

Let's assume that this time we want an equal-value, high-pass, second-order Butterworth filter with a corner frequency of 1kHz.

Well, in fact we can skip the rest of the steps since we have already designed it! The design values for an equal-value, high-pass Butterworth filter at a given corner frequency are identical to those of the low-pass filter – all you have to do is swap the positions of the Rs and Cs. Fig.9-12 show 1kHz Butterworth low/high-pass filters and their respective assembled PCBs.

Design notes

In audio designs we keep the gain resistors fairly low to minimise noise. However, some designers will be concerned about DC off-sets caused by op amp input currents, so they try to ensure that the total resistances 'seen' by the inverting and non-inverting op amp inputs are the same, or at least very similar.

Cascading Sallen-Key filters

Connecting one second-order filter after another will give a fourth-order response. These filters are popular in high power public address systems. Just as with the second-order filters, all the Rs and Cs are equal. However, to obtain a proper Butterworth response the gains of both sections have to be independently designed. For an equal-value Butterworth fourth-order the first section should have gain of 1.152 and the second section has a gain of 2.235, as shown in Fig.13. Using the 2.2kΩ lower arm feedback resistor as before the resulting resistor values are 330Ω and 2.7kΩ respectively. The total gain of this system is 2.58 or 8.2dB. I have built several active crossovers with this basic topology. A nice advantage of this design is that the corner frequency can simply be changed by plugging in DIL headers populated with four capacitors. This technique was used for an active loudspeaker crossover design in Ben Duncan's *Hi-Fi News and Record Review* article of Feb 1981.

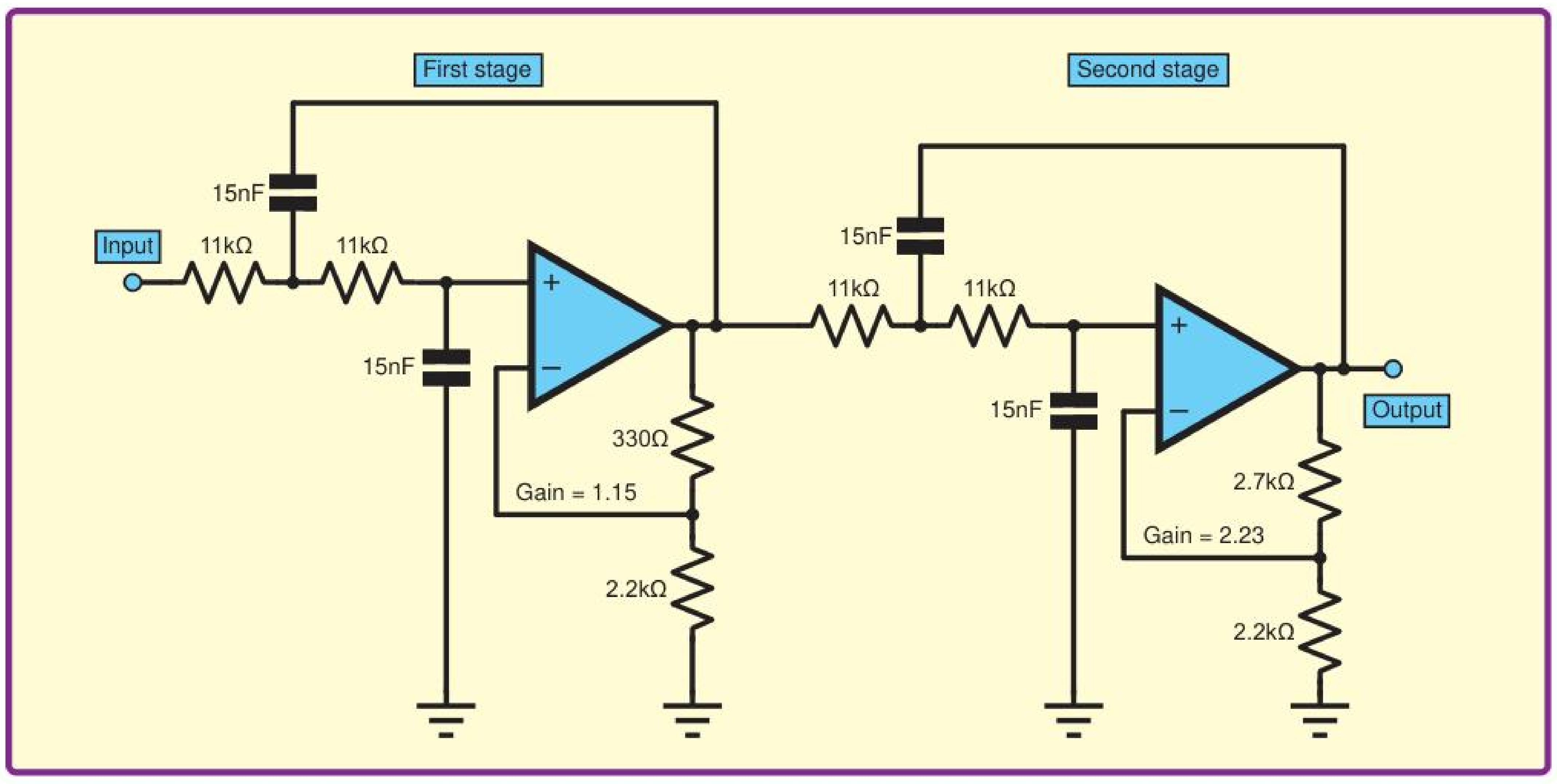


Fig.13. Practical fourth-order 1kHz low-pass Butterworth filter

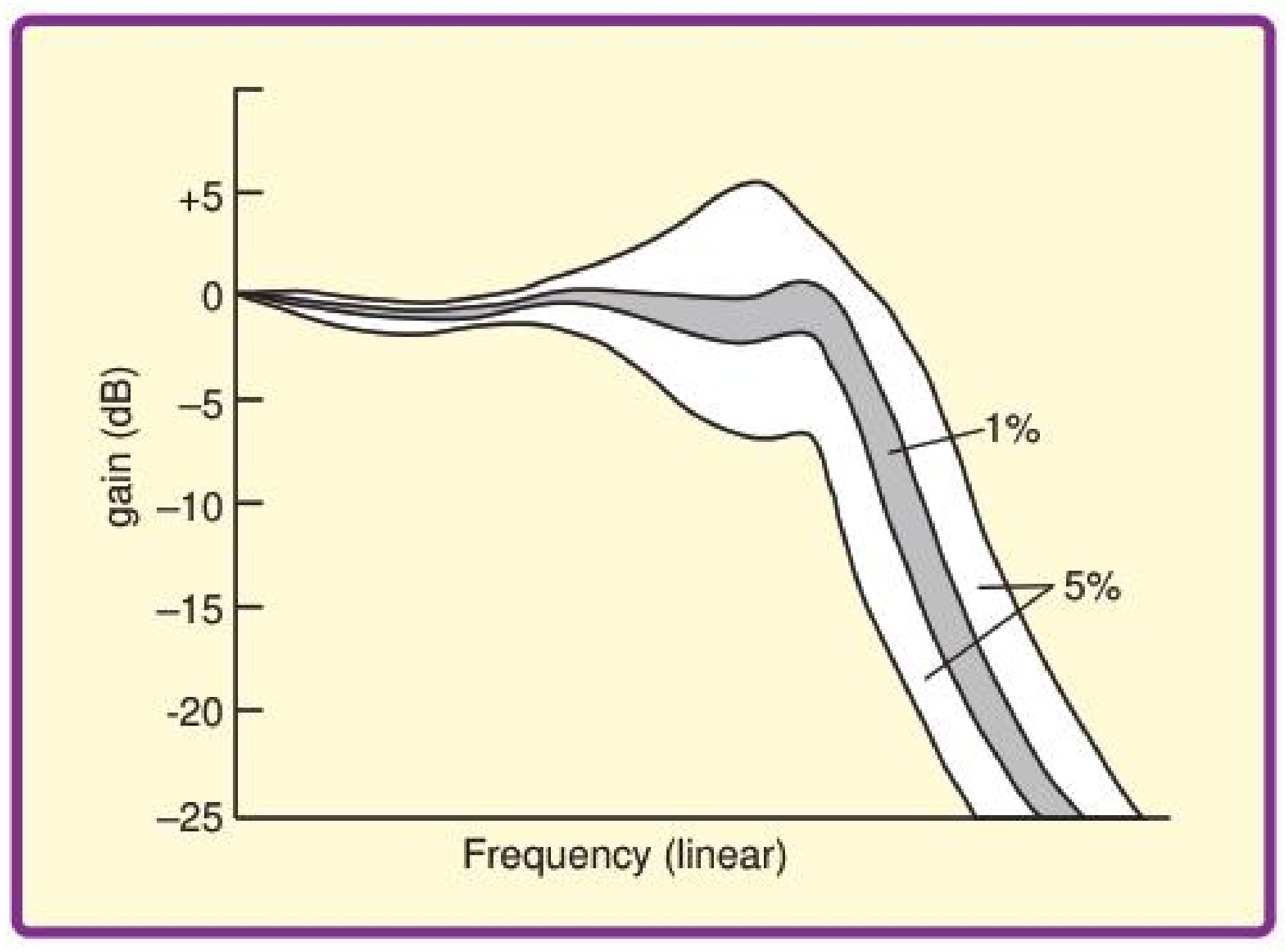


Fig.14. Worst-case deviations from ideal response due to component tolerances, from The Art of Electronics

It is important to put the higher-gain section second for maximum headroom, as opposed to lowest noise. In audio, work a fourth-order Butterworth filter is considered about the limit before the sound begins to sound artificial and coloured. However, if you fancy designing a sixth- or eighth-order monster of a filter, then the cascaded gains are: 1.068, 1.586, 2.483 and 1.038, 1.337, 1.889, 2.610 respectively. Fun to try, but perhaps not the best for high fidelity!

Occasionally, a third-order filter is required. This can be made by putting a passive RC filter in front of a second-order Sallen-Key. The impedance of the RC filter must be at least ten-times lower than the input impedance of the second-order section to minimise interaction. The gain on the active filter must be upped to 2.

Band-pass filters

Audio band-pass filters normally pass a range of frequencies rather than picking out just one, so cascading a high-pass and low-pass filter is usually used. In this case, there are two corner frequencies and the pass band curve is flat topped rather than a peak – for example, a filter for the mid-range speaker in a PA system. This would involve a fourth-order high-pass followed by a fourth-order low-pass, using a total of four op amps.

Component selection

The Sallen-Key configuration is sensitive to component values, since there are a lot of interactions and some positive feedback, which multiply errors. The effect is higher for the equal component version. Component tolerances of 5% can give worst case variations of ±7dB on the curve (Fig.14) according to the graph published in *The Art of Electronics* (Figure 5.12, page 271, 2nd edition).

It is easier to design using the more accurate (and expensive) E24 value range of capacitors. Odd value resistors are not a problem, since E96 1% values are easily available, such as the MSR25 series from Element 14. It's also physically easier and cheaper to combine resistors than capacitors to optimise or tweak values.

Acceptable consumer audio circuits usually use 5% polyester capacitors with 1% metal-film resistors. Upgrading the capacitors to 1 or 2.5% polystyrene or polypropylene capacitors brings it up to a professional level. Interestingly, Doug Self discovered that the capacitor distortion of the non-bootstrapped capacitor (C2 in Fig.6 and C2 in Fig.7) in the Sallen-Key is more significant because it has a higher voltage across it.

Back to the unity-gain Sallen-Key

We introduced the Sallen-Key topology as an active filter with a unity-gain buffer, but then adopted a design with some gain. We did this largely to start off with an ultra-simple route to filter design. However, this gain can be a problem in audio systems – you need to take care that it doesn't sap too much headroom or boost hiss. Also, it can be tricky if you want to switch a filter in and out, since the volume will be louder with the filter switched in. So, while it is clear that the unity-gain approach has advantages, the problem is that it is more complicated to design. How much more complicated? Fortunately, not much – but you do need to be careful that all the Rs and Cs don't get muddled up.

Designing a unity-gain, low-pass second-order Butterworth filter

We can follow the four steps we used for the equal-value version, but with a tweak to steps 3 and 4.

Step 1 – definition

Let's assume we want a low-pass, unity-gain, second-order Butterworth filter with a corner frequency of 1kHz.

Step 2 – choose R, the filter resistors

Although this is not an equal-value design, for a low-pass filter we can still make R1 = R2 = R and we'll stick with the 10kΩ recommended earlier. So, R1 = R2 = R = 10kΩ

Step 3 – calculate capacitor C values

This is where we diverge from the earlier design algorithm. We start off as before using the corner frequency equation to find a value for *C*, which will be 15nF. Now, however, we need to scale this value for both C1 and C2. Again, the mathematics to determine the scaling can be unpleasant, so please just it take on trust that the two scale factors are 1.414 for C1, and 0.707 for C2 – this gives:

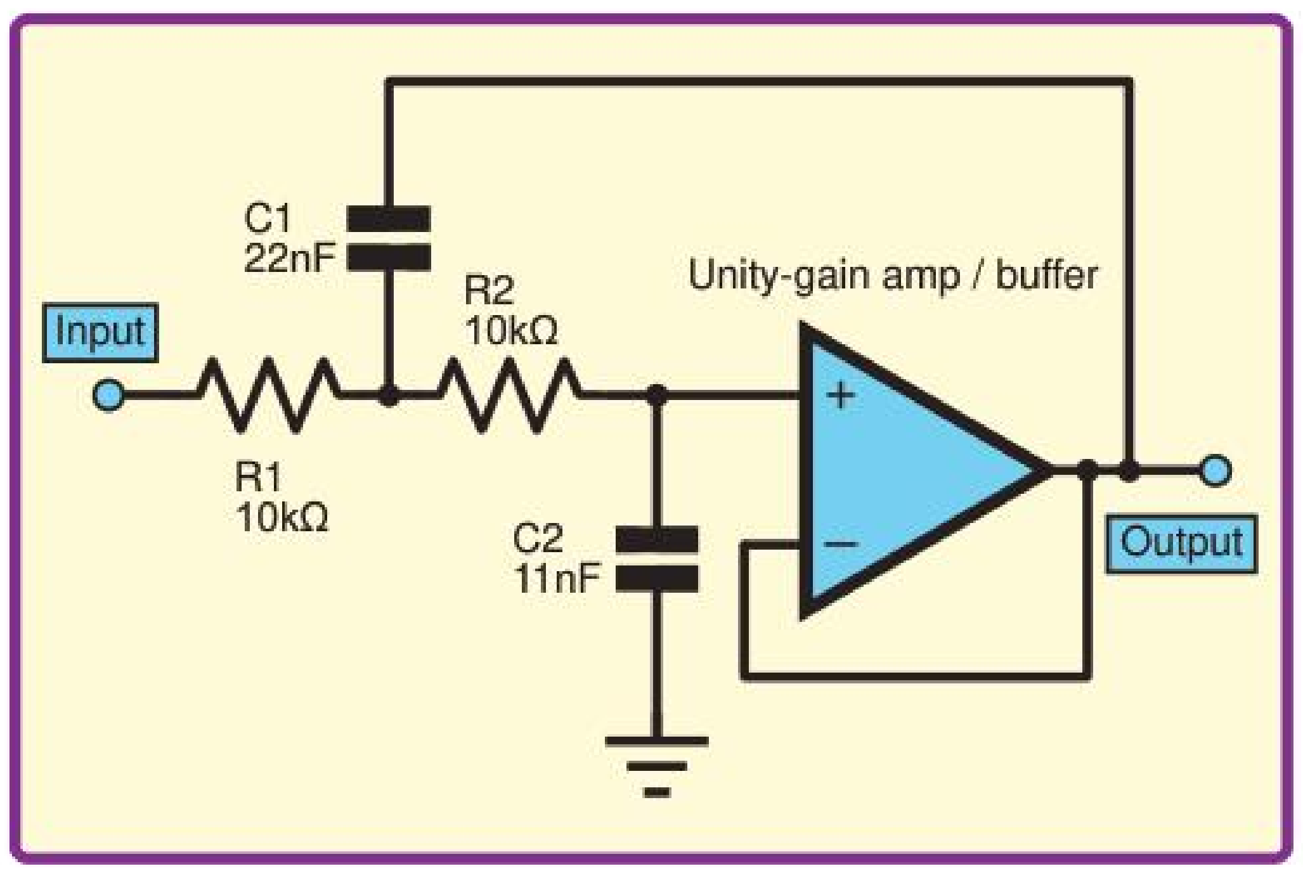


Fig.15. Unity-gain Sallen-Key 1kHz low-pass Butterworth filter

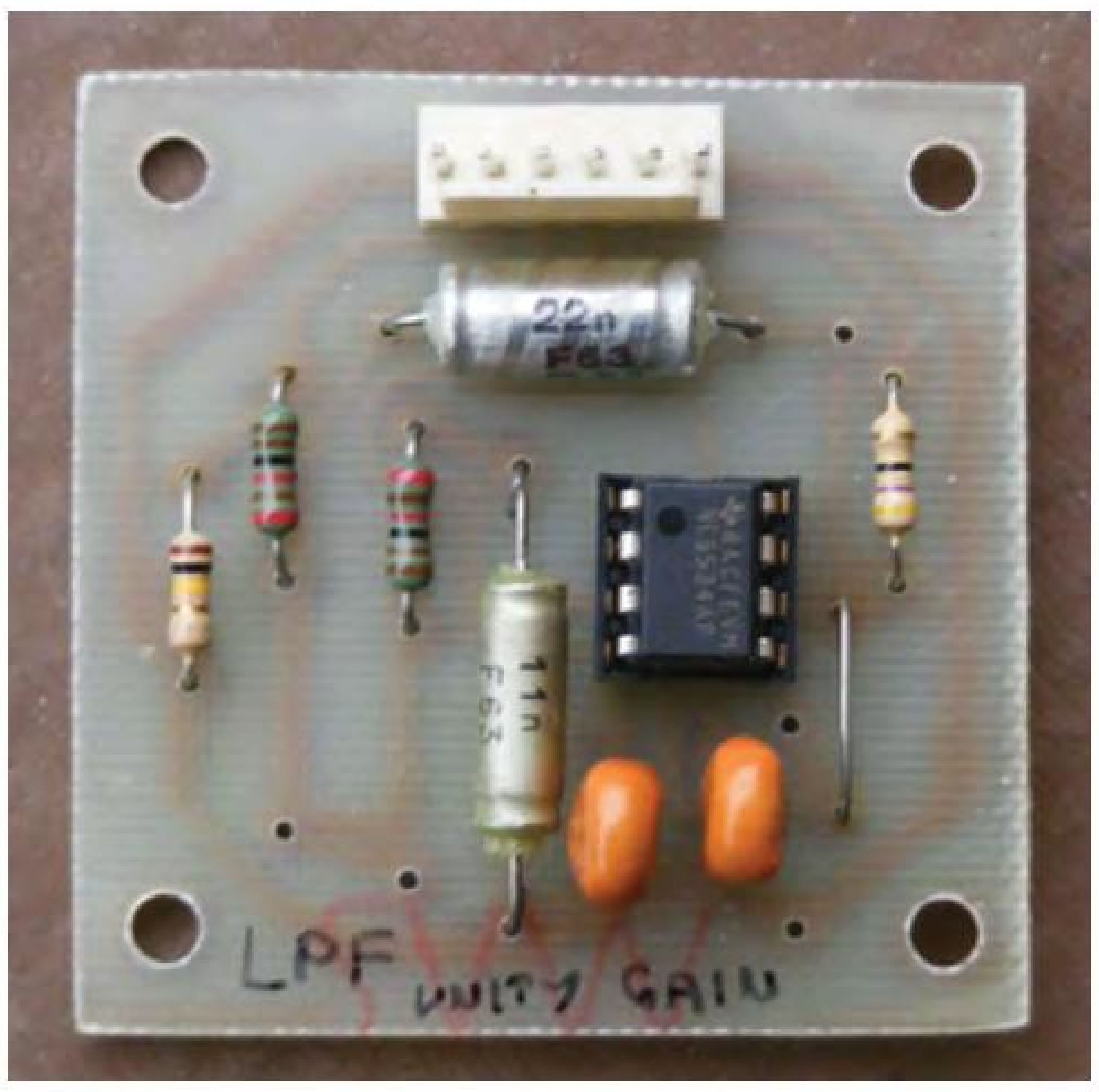


Fig.16. Assembled unity-gain 1kHz Butterworth low-pass filter. Note link on PCB to make op amp into buffer

$C1 = 15.9 \times 1.414 = 22.5\text{nF}$
$C2 = 15.9 \times 0.707 = 11.21\text{nF}$

The nearest E24 capacitor values are 22nF and 11nF, as shown in Fig.15. A completed PCB is in Fig.16. Do remember when using nearest values it is necessary to check the response for deviations. The Sallen-Key configuration amplifies the effect of component tolerances and deviations.

Step 4 – set the gain of the op amp

This is the easy bit – the gain is one and no calculations are needed since the gain-setting resistors are replaced with a short and open circuit.

Designing a unity-gain, high-pass second-order Butterworth filter

The question now is have we automatically designed the high-pass equivalent as we did with the equal-value filter. The short answer is 'no', but not much more work is needed.

To derive the high-pass circuit we have to transpose the position of the capacitors and resistors – as before. This time the capacitors are equal, but the resistors have to be scaled to set the damping. R1 is scaled by 0.707 and R2 is scaled by 1.414.

A good choice of capacitor would be 15nF and for a corner frequency of 1kHz, the resistor value is calculated to be R= 11kΩ, resulting in R1 = 7.5kΩ and R2 = 15.6kΩ. (These values would

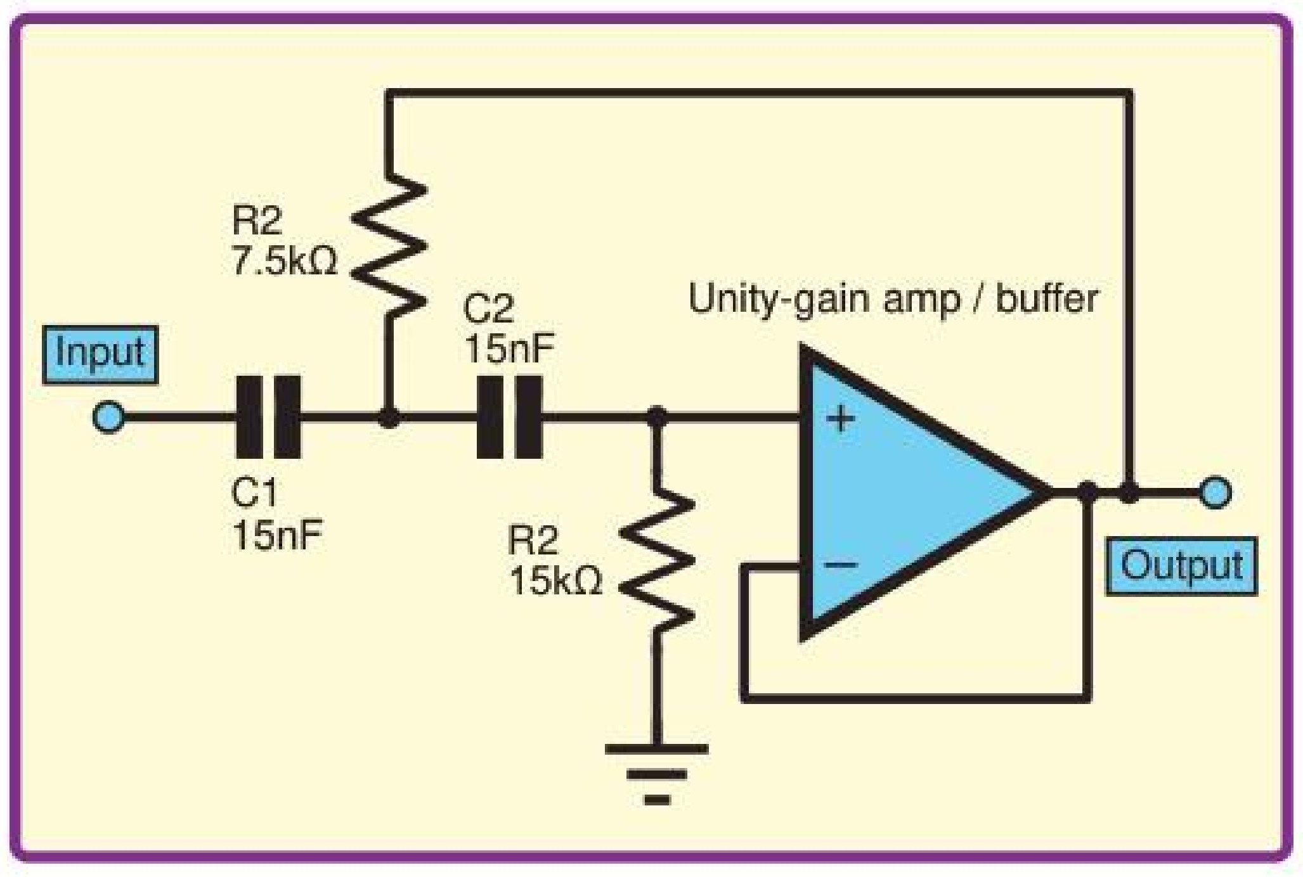

R2
7.5kΩ
C2
15nF
Unity-gain amp / buffer
Input
+
–
C1
15nF
R2
15kΩ
Output

Fig.17. Unity-gain Sallen-Key 1kHz Butterworth high-pass filter

actually result in a corner frequency of 0.96kHz, but that is close enough to 1kHz.) The final circuit is shown in Fig.17 and the completed PCB in Fig.18.

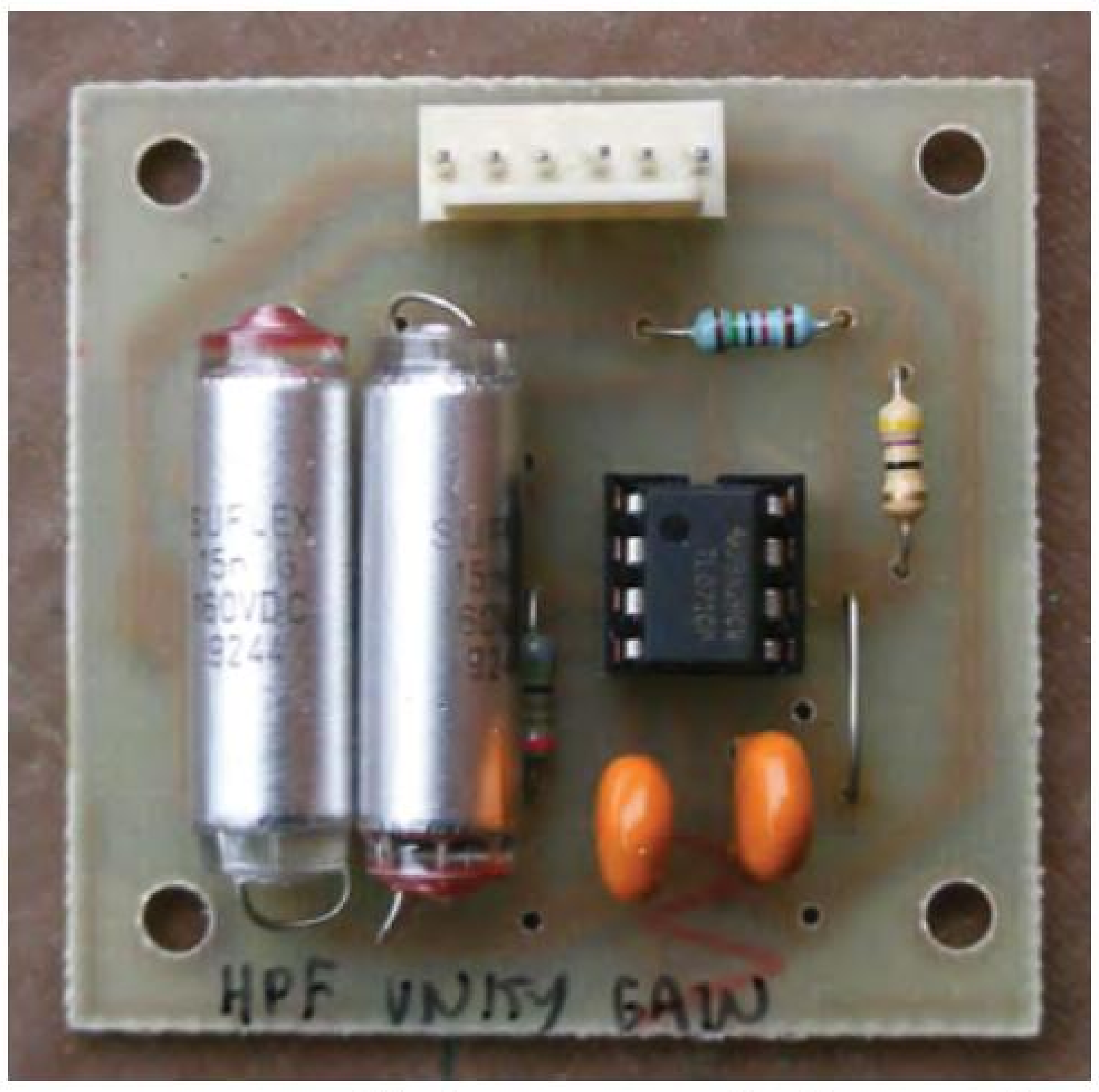

HPF UNITY GAIN

Fig.18. Assembled unity-gain high-pass filter PCB. Note PCB can accommodate big polystyrene capacitors needed for high accuracy

Practical circuit and PCB

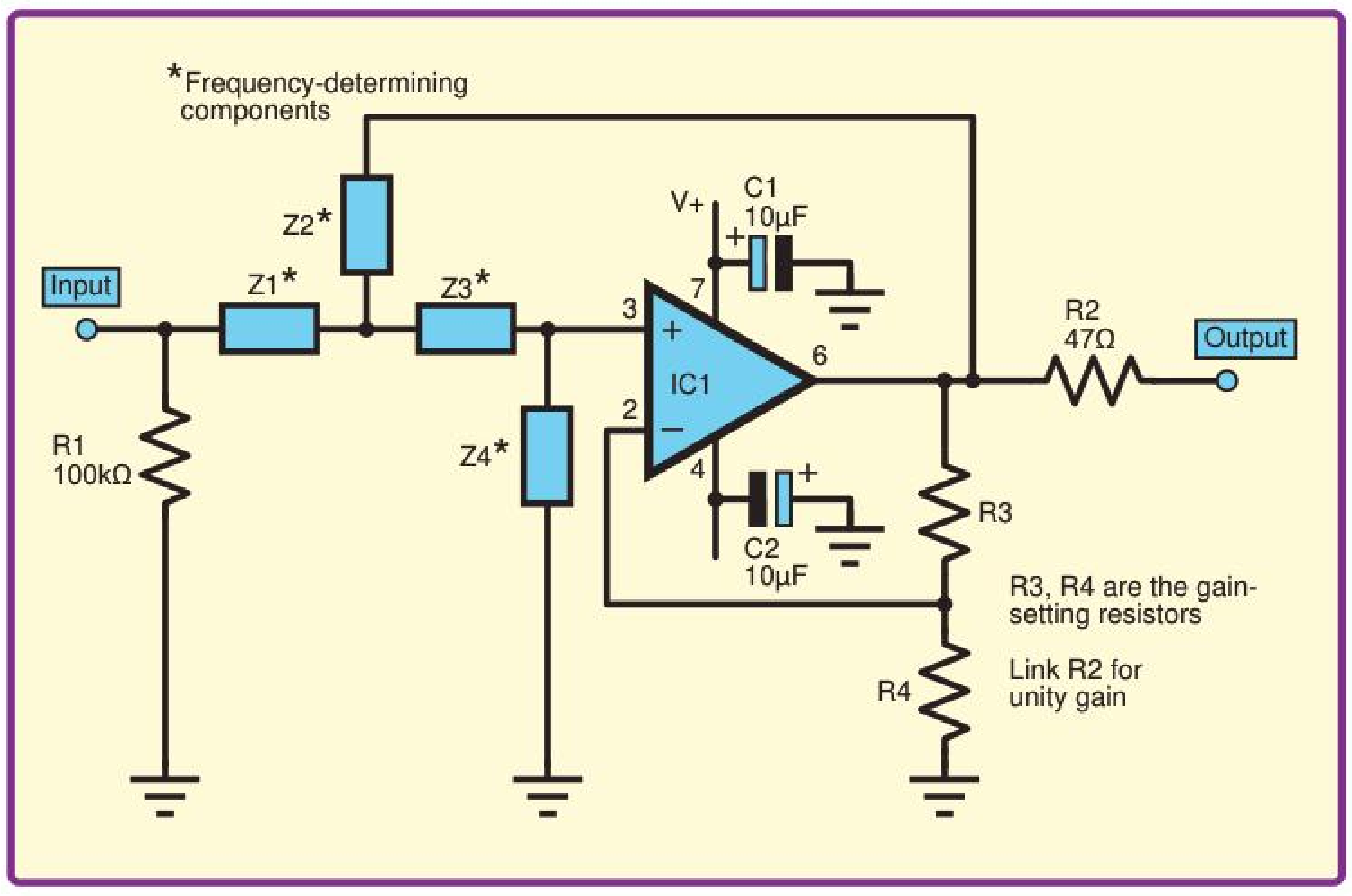

*Frequency-determining components
Input
Z1*
Z2*
Z3*
Z4*
R1
100kΩ
V+
C1
10µF
+
3
7
6
2
4
IC1
C2
10µF
R2
47Ω
Output
R3
R4
R3, R4 are the gain-setting resistors
Link R2 for unity gain

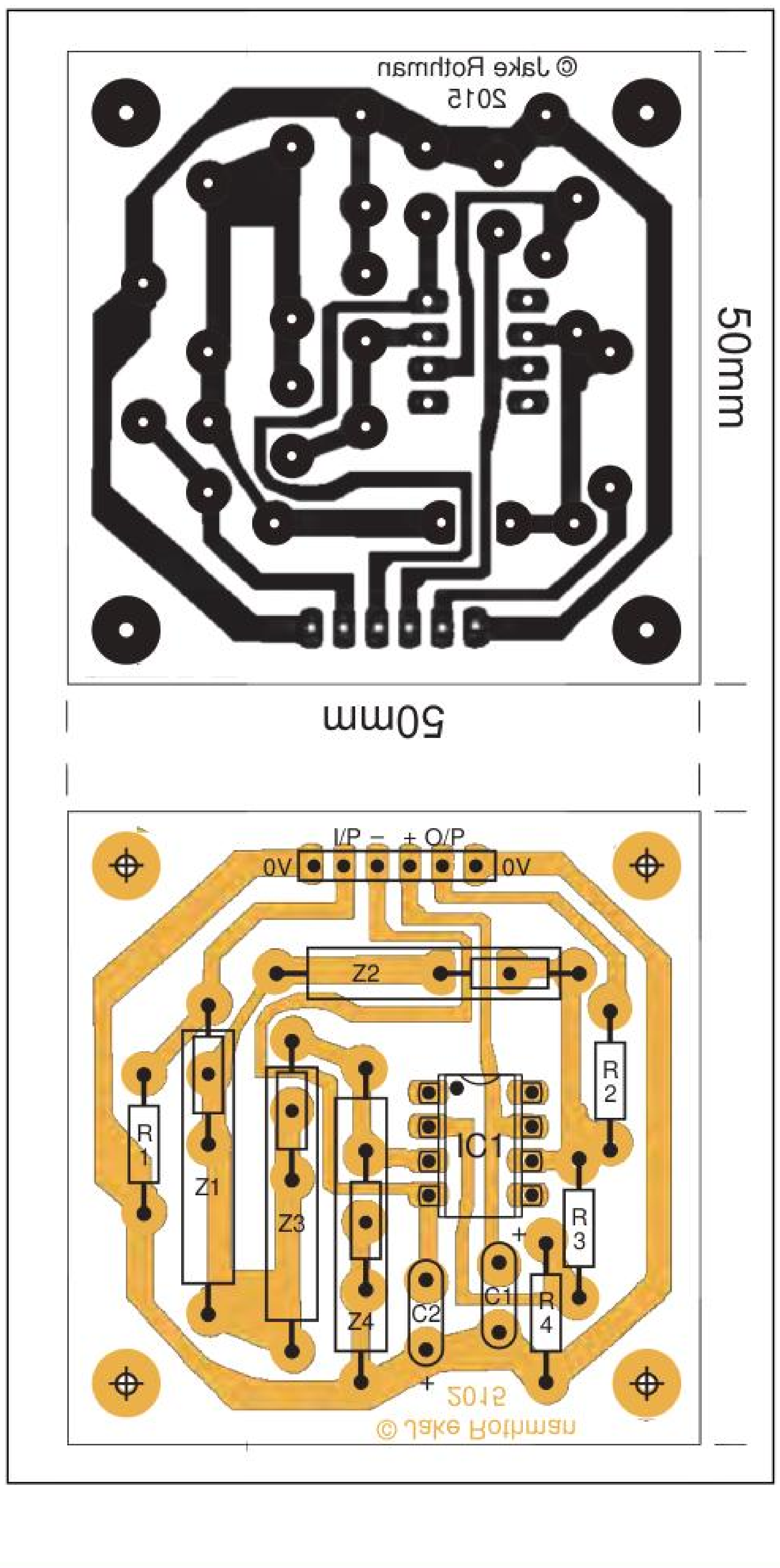
Fig.19. Circuit for universal Sallen-Key board

Fig.19 shows a general, second-order Sallen-Key circuit for equal-value and unity-gain designs. The simple PCB layout and component layout are shown in Fig.20. Note that if a 5534 op amp is used, a 22pF stability capacitor will have to be soldered across pins 5 and 8. The filtering components, which can either be resistors or capacitors are dual outline and denoted by Z1 to Z4. Large axial polystyrene capacitors can be accommodated.

Resistor R1 is necessary to provide a DC path to ground to prevent it going off-set in the low-pass filter configuration. R2, which can be 47Ω to 100Ω is needed to stop oscillation when feeding capacitive loads, such as screened leads.

Design aids

Naturally, the Internet is awash with advice and it is well worth looking out for online calculators to check calculations and aid design. One that I particularly like and use for most filters is available at: **sim.okawa-denshi.jp/en** – but do watch out, overuse of these tools can make you lazy – always check their answers!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2015
50mm
50mm
I/P
O/P
0V
0V
Z2
R1
Z1
Z3
IC1
R2
R3
Z4
C2
C1
R4
+
2015
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Fig.20. PCB component overlay for universal Sallen-Key board. Note Z designation for frequency-determining components. It will accommodate the four variations given here. Unity-gain or equal-component versions of a low-pass or high-pass, second-order Butterworth filter

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Max's Cool Beans

By Max The Magnificent

Colourful chronography

A few months ago, my chum Duane Benson sent me a 60-element NeoPixel ring, along with a custom Arduino-compatible circuit board he'd created. Actually, this ring is composed of four 15-element quadrants soldered together (Adafruit part #1768 – **http://bit.ly/1MRBegP**), but let's not quibble here. As soon as I powered this little scamp up, it was apparent it was functioning as a clock. As I always say, 'Show me a flashing LED and I'll show you a man drooling,' so you can only imagine the effect 60 of the little rascals had on my nervous system.

I really liked Duane's initial choice of colors and the overall look-and-feel of his clock, but it wasn't long before I began to think about how I might go about enhancing the effect. For example, instead of having the 'seconds' indicator advancing around the clock at a stately pace ('Thousand-one, thousand-two, thousand-three, …'), we could have it race all the way around the circle until it returned to its current origin, at which point it could 'knock' the previous instantiation into the next element.

Adafruit offer 24-element and 12-element rings, both of which lend themselves to clock-type projects. The thing is that a bunch of us decided to have a competition to see who could use different colours and effects to create the most fun, interesting, and intuitive representation of a clock. The prime goal is that anyone seeing this for the first time would immediately say to themselves: a) 'That is a clock,' and b) 'The time is…'.

We decided that we should all use one each of 60-, 24-, and 12-element rings, but after that the implementation was up to each person. Also, additional points will be awarded for any enhanced capabilities, presentation, and so forth. Of course this is a lot of effort when you consider that the only prize is bragging rights, but we are engineers – this is what we do!

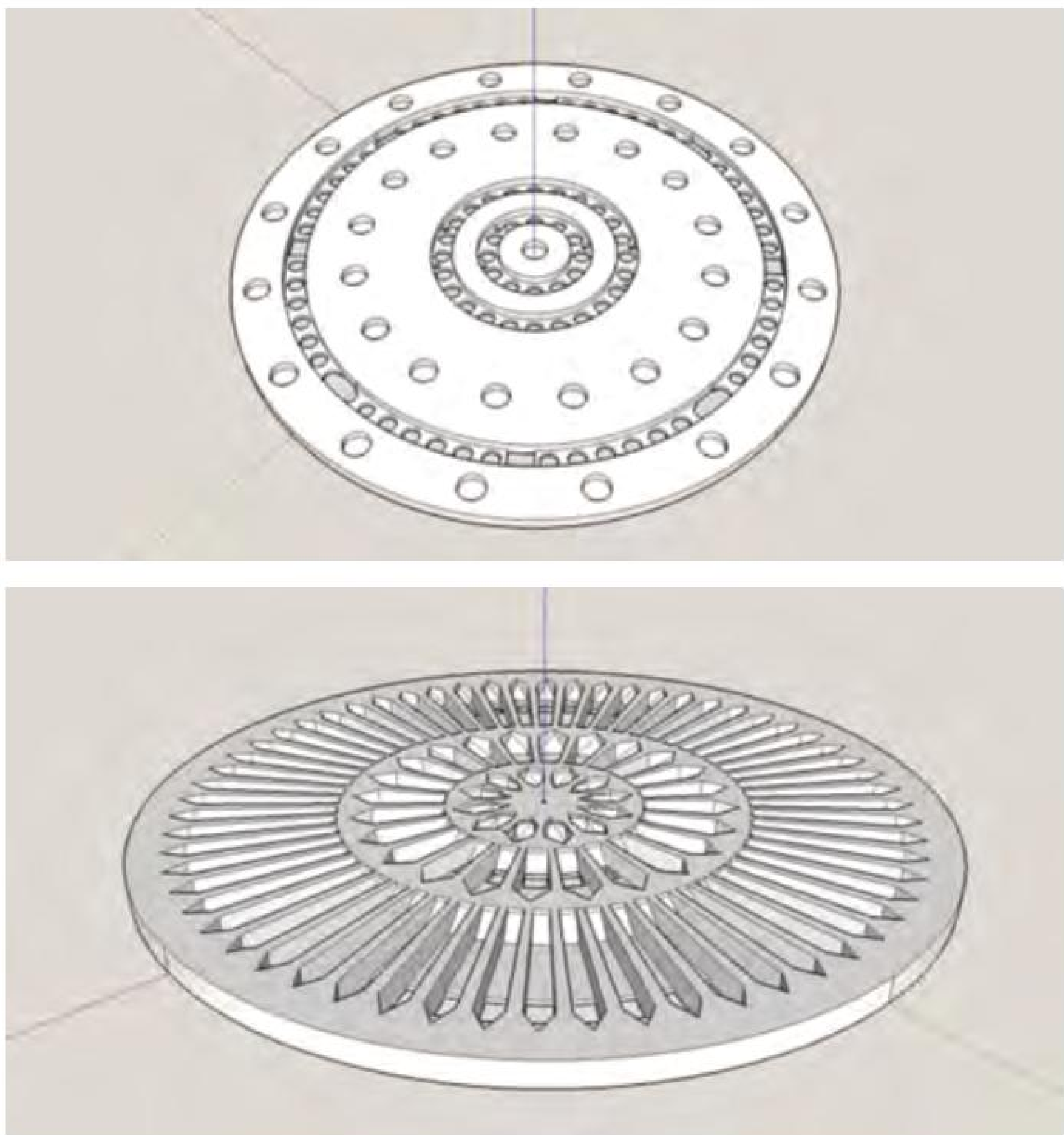


Fig 1. 3D views of base (top) and face (bottom)

But it's got no hands!

An engineer in my office, Ivan Cowie, decided to join the competition, and he's augmented his clock with speech recognition and synthesis capabilities. Another friend – Steve Manley in the UK – has come up with a really tasty colour scheme. Unfortunately, when Steve took his prototype into his office to show it to his colleagues, the tea lady was less than enthused, saying: 'It doesn't look much like a clock – it doesn't even have any hands!'

Well, you can't argue with facts like that, so when Steve returned home he used a 3D drawing package to create a base-plate to hold the three rings and a face-plate to channel the light from the LEDs to generate the impression of having hands. Steve was kind enough to share these files with me, and I had my own versions printed using the service offered by **shapeways.com**

Do you recall my *Bodacious Acoustic Diagnostic Astoundingly Superior Spectromatic* (*BADASS*) display project (**http://bit.ly/1I5ncTc**)? Well, one of the things I've done is to take the audio spectrum analyser card design I created for that project and added one to my *Cunning Chronograph*, see Fig 2, where we see the little beauty in its music-display mode.

And speaking of beauty, what do you think about my cabinet? This was created by my carpenter friend, Bob, including the hand-carved Celtic knot on the ring surrounding the LEDs. Bob has a friend who applied the silver gilding to the knot, and I have to say that the resulting effect looks amazingly tasty.

I'm also going to add a 9-DOF (degrees of freedom) MEMS sensor, featuring a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer. The idea is that if you pick the six-sided cabinet up and place it on a different face, the clock display will slowly rotate back to its home position. Furthermore, if you lay the clock on its back, it will transition into being a compass. (Ironically, the one mode I've not really started working on yet is the time-keeping function!)

Cunning coding tips and tricks

Now, before we go any further, I should remind you that I'm a hardware designer by trade – I only dip my toes and dabble in the software waters. Software guys and gals will probably roll their eyes in amusement and derision at the coding tips and tricks I'm going to talk about. By comparison, hardware-centric folks may well find these concepts to be capriciously cunning.

Just to set the scene, and for the sake of simplicity, let's assume we're working with an 8-element ring, as illustrated in Fig.3. We can visualise this as being instantiated as ring[8], with eight elements numbered from 0 to 7 (I've shown element 0 as being darker only to provide a point of reference).

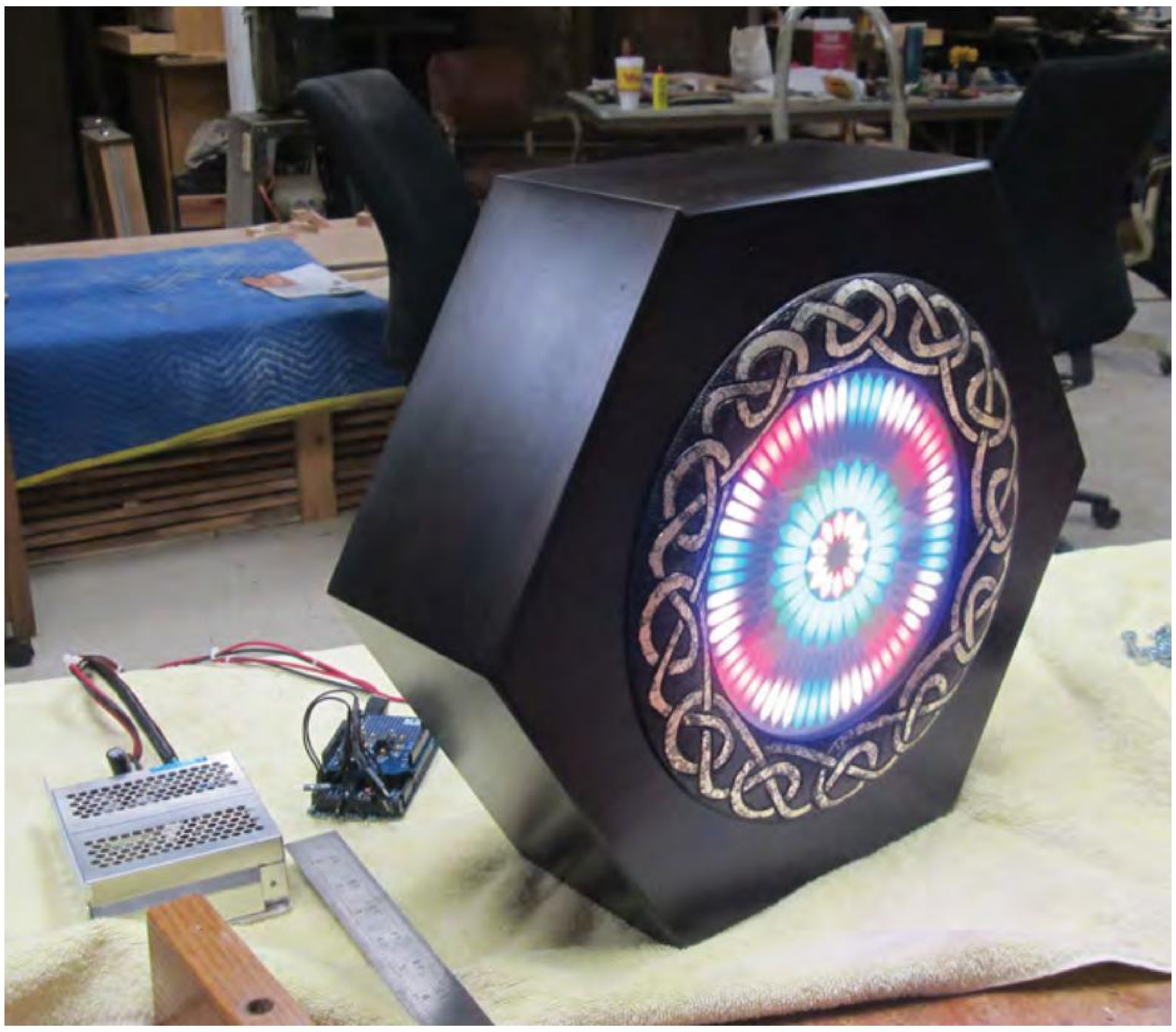


Fig 2. The Cunning Chronograph *in music-display mode*

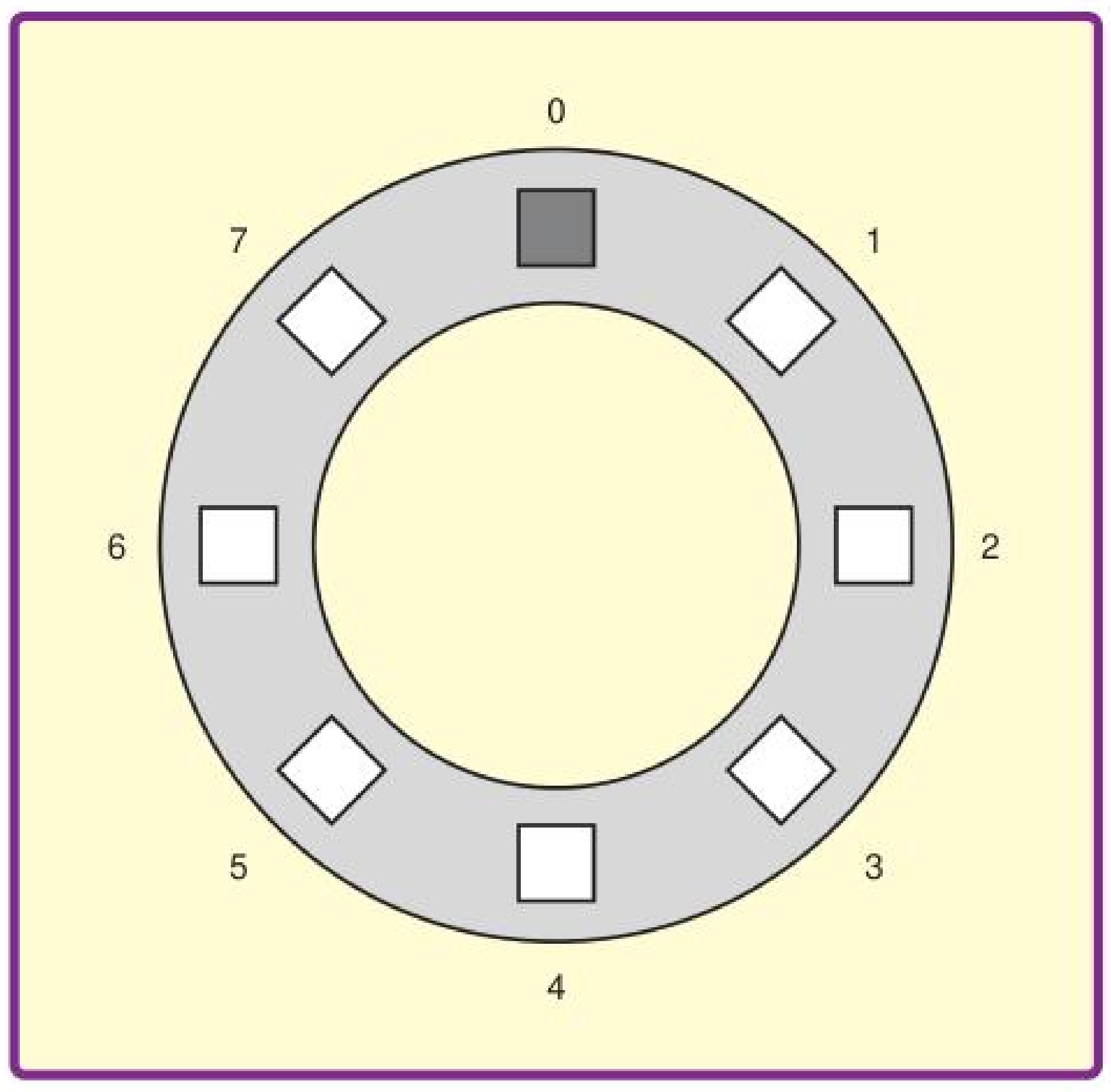


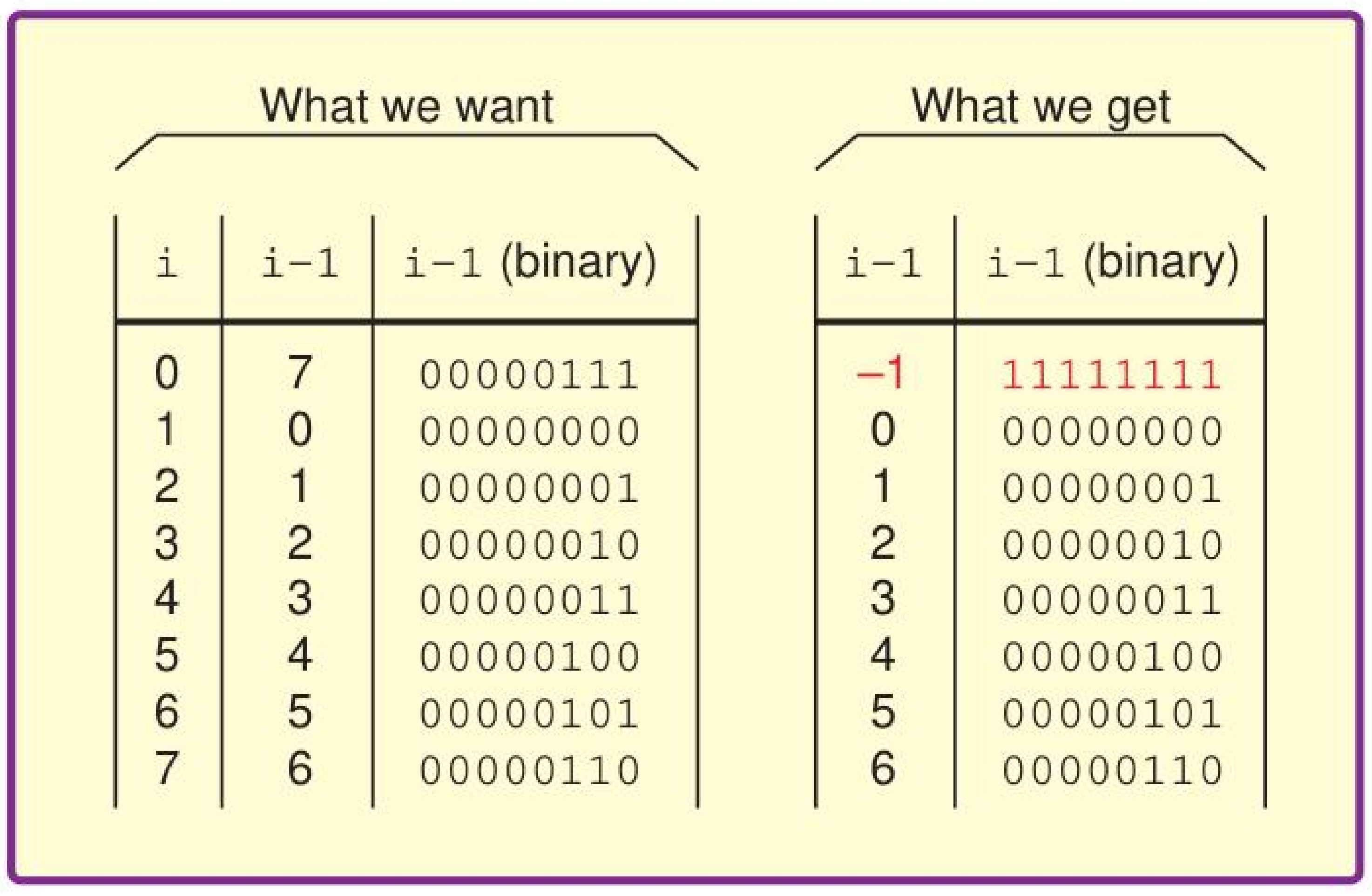
Fig 3. An 8-element ring

As you may recall from my previous articles on using WS2812-based NeoPixels (see *EPE* July, Aug, and Oct 2015), we call the `setPixelColor()` function to define the R, G, and B (red, green, and blue) values of each pixel in the Arduino's memory, and then we call the `show()` function to stream these values out of the Arduino into the NeoPixel ring.

Let's start with a really simple example. What we want to do is have a single red pixel racing clockwise around the ring. In order to do this, we need to turn one pixel on and turn the previous pixel off. As a starting point, consider what would happen if we were to call the following snippet of code over and over again:

```
for (i = 0, i < 8; i++) {
  ring.setPixelColor(i,255,0,0);
  ring.setPixelColor((i-1),0,0,0);
  ring.show();
  delay(100);
}
```

The idea is that we light up pixel `i` (where `255,0,0` means the red sub-pixel is fully on and the green and blue sub-pixels are off) and we turn off pixel `i`–1. The only problem is that this isn't going to work because of one of the end conditions (it's usually the end conditions that nobble you when you're least expecting it). In order to understand the problem, consider the table shown below in Fig.4.



What we want			What we get	
i	i-1	i-1 (binary)	i-1	i-1 (binary)
0	7	00000111	–1	11111111
1	0	00000000	0	00000000
2	1	00000001	1	00000001
3	2	00000010	2	00000010
4	3	00000011	3	00000011
5	4	00000100	4	00000100
6	5	00000101	5	00000101
7	6	00000110	6	00000110

Fig 4. It's the end conditions that can nobble you

In this case, we run into issues when we light up element `i` = 0 and try to turn off element `i`–1. What we want to do in this case is turn off element 7, which is 00000111 in binary. However, when `i` = 0, then `i`–1 = –1, which is 11111111 in binary. (If you aren't sure where this 11111111 value came from, Google 'two's complement'; for our purposes here, you'll just have to take my word for it – have I ever lied to you before?)

Now, we could modify our snippet of code to add a test along the lines of, `If i = 0 then turn off element 7, otherwise turn off element i-1`, but I find this to be a tad awkward and aesthetically unpleasing. As an alternative, we can use the & bitwise AND operator (**http://bit.ly/1WLBpJS**) as illustrated in the following code snippet:

```
for (i = 0, i < 8; i++) {
  ring.setPixelColor(i,255,0,0);
  ring.setPixelColor(((i-1) & 0x7),0,0,0);
  ring.show();
  delay(100);
}
```

In this case, 0x7 is the hexadecimal equivalent of 00000111 in binary. When `i`-1 = 11111111 and we perform a bitwise AND with 00000111, we end up with 00000111 (decimal 7), which is what we wanted in the first place. By comparison, when `i`-1 = 00000000 through to 00000110 (decimal 0 through to 6), the bitwise AND has no effect, which is also what we want.

What about if we wish the active element to rotate anticlockwise around the ring? In fact, the above code snippet works for that case also, but I'll leave you to draw out the table and prove that this works to your own satisfaction.

Now, the above may seem to be rather trivial, but it will provide a great starting point for the discussions that are to come in my next column on this topic. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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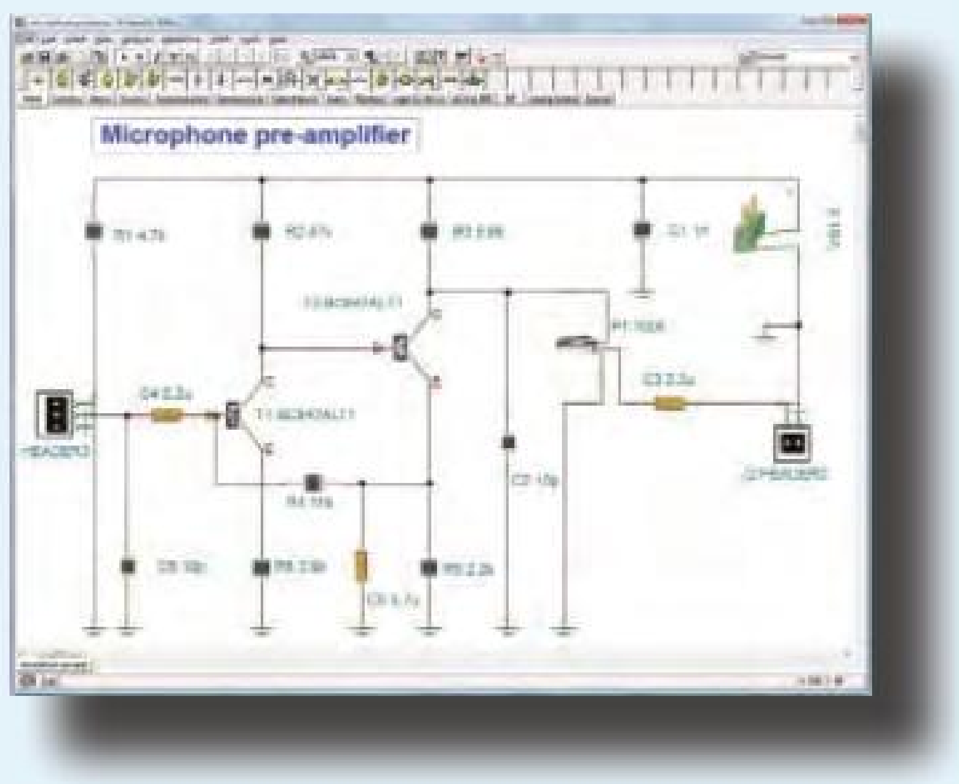

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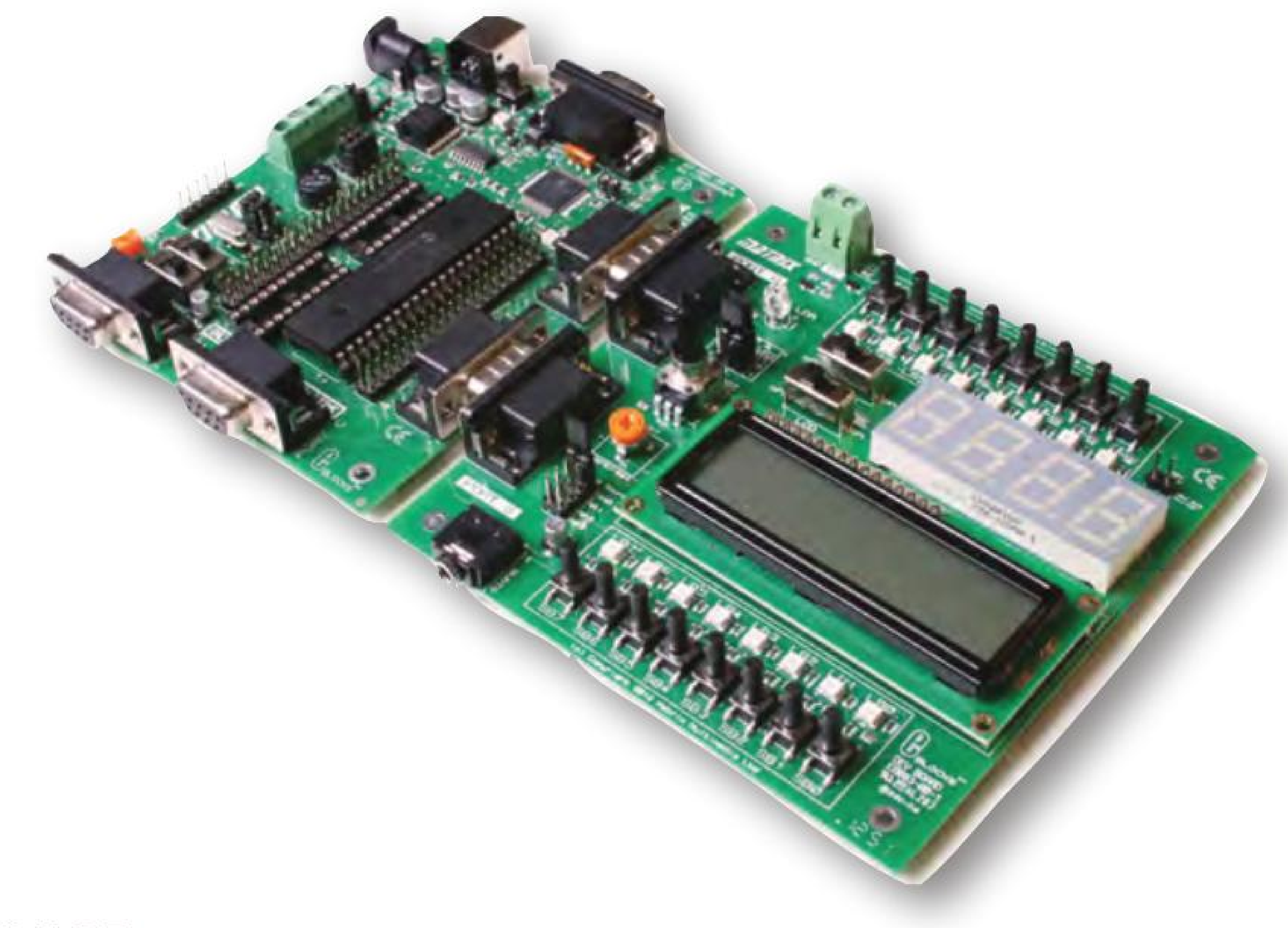

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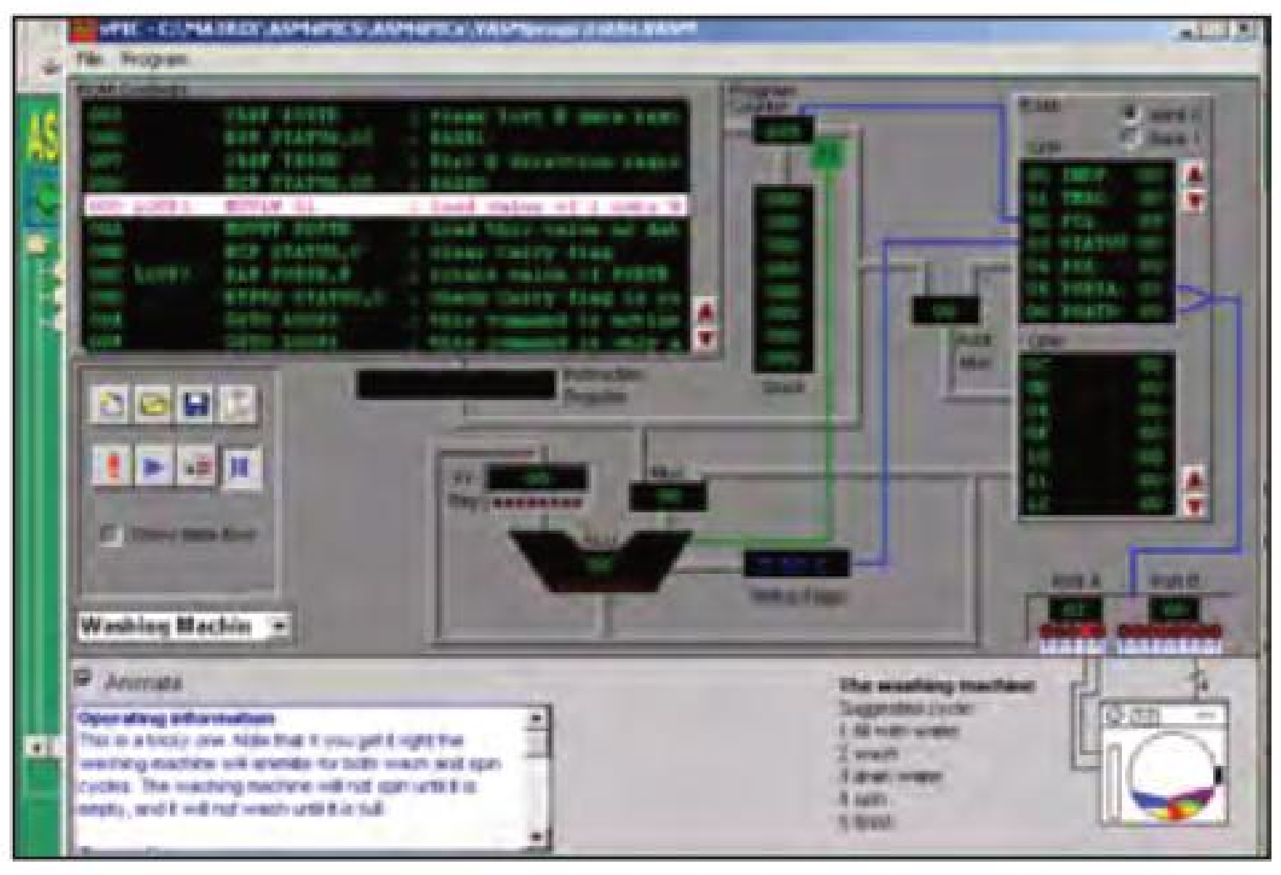

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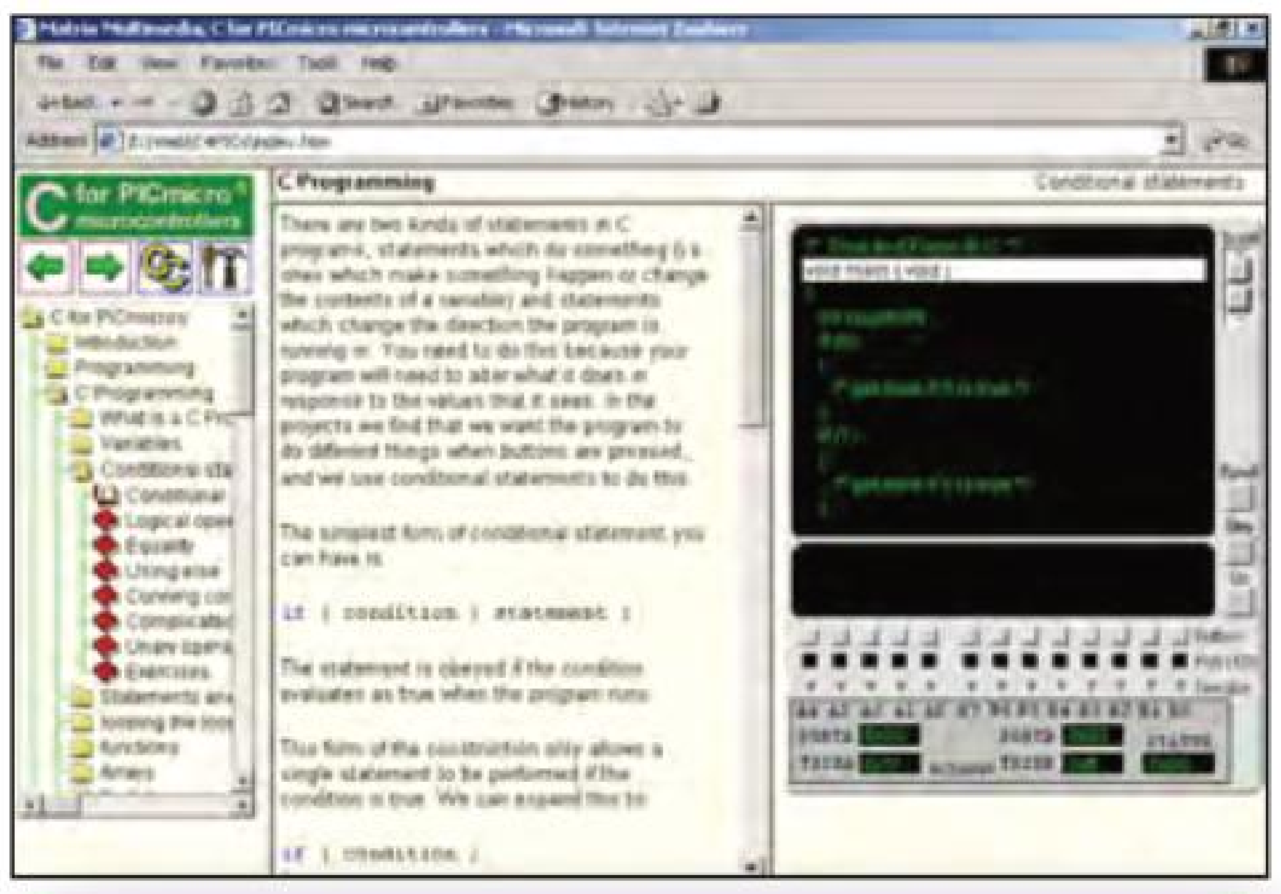

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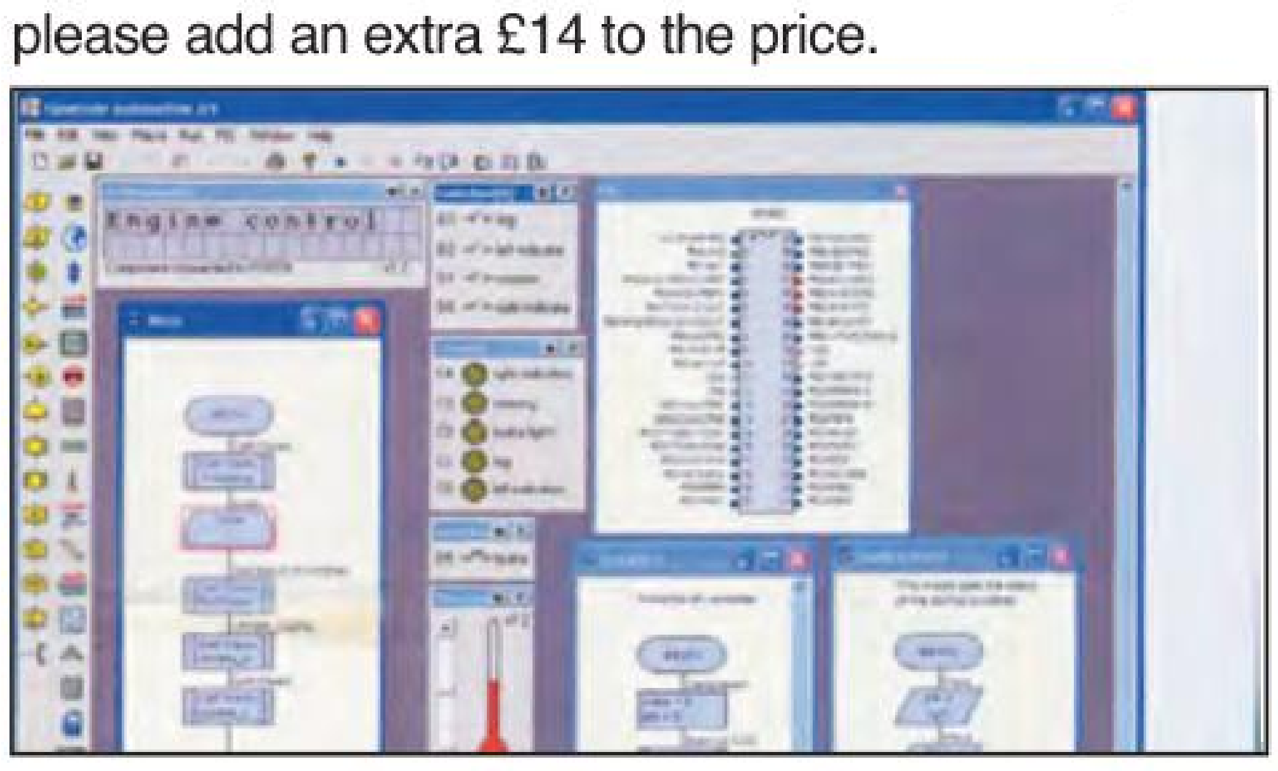

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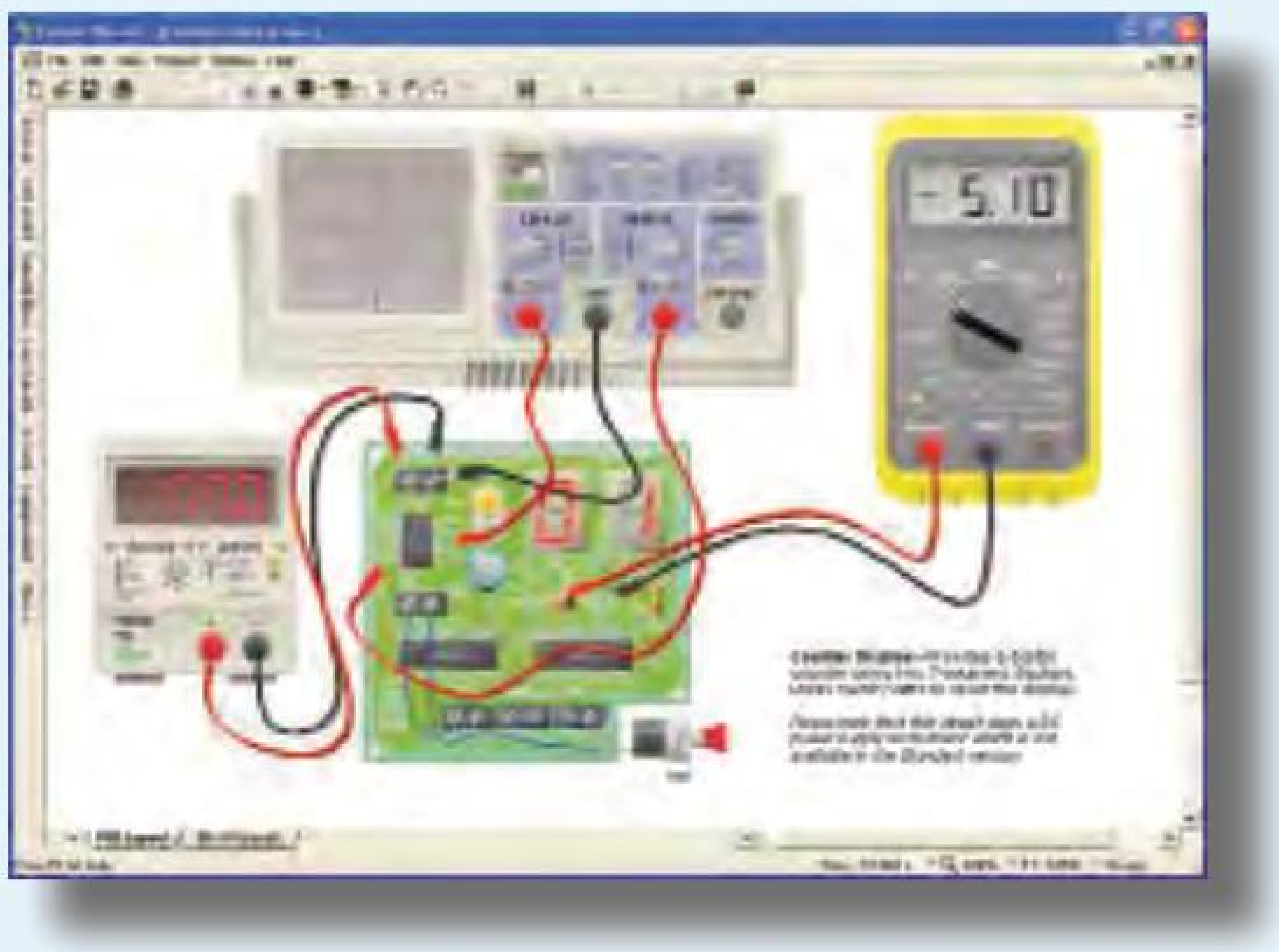

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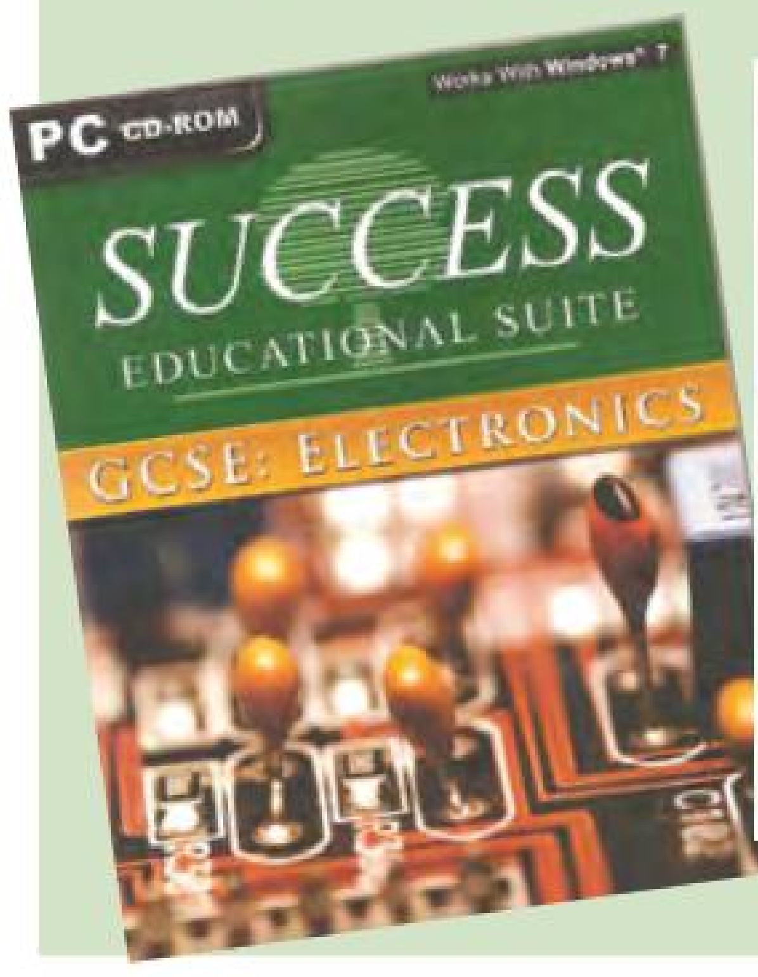

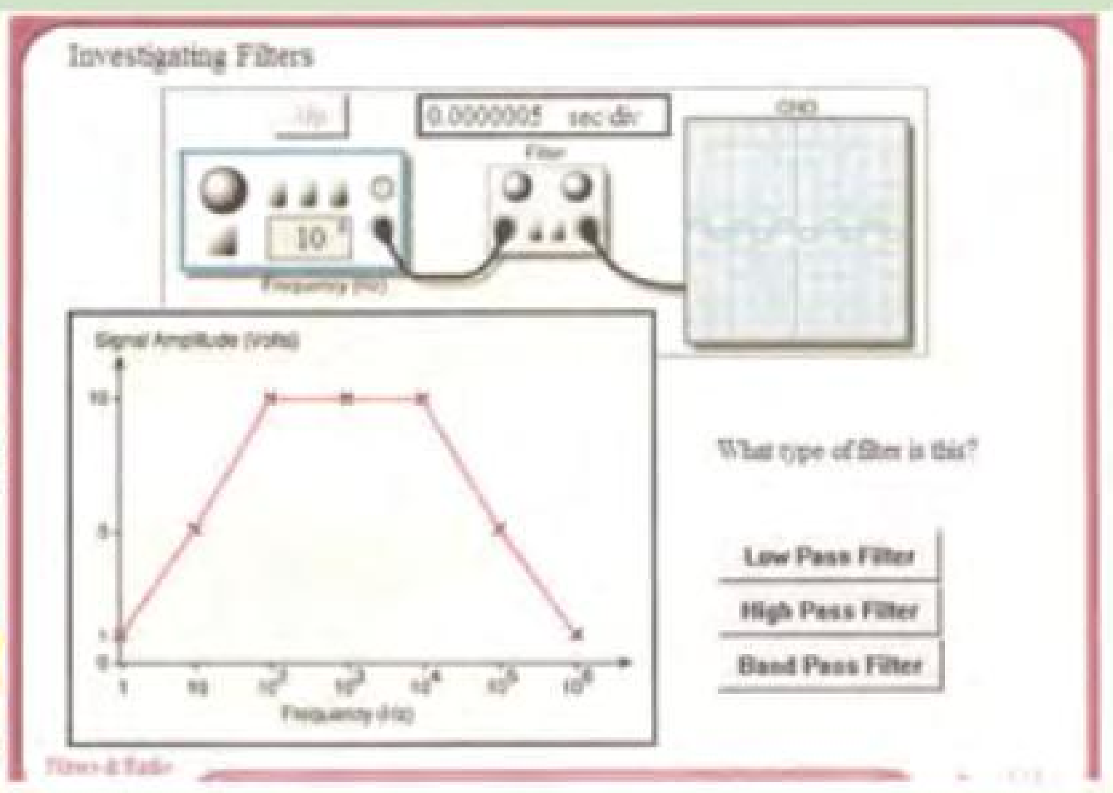

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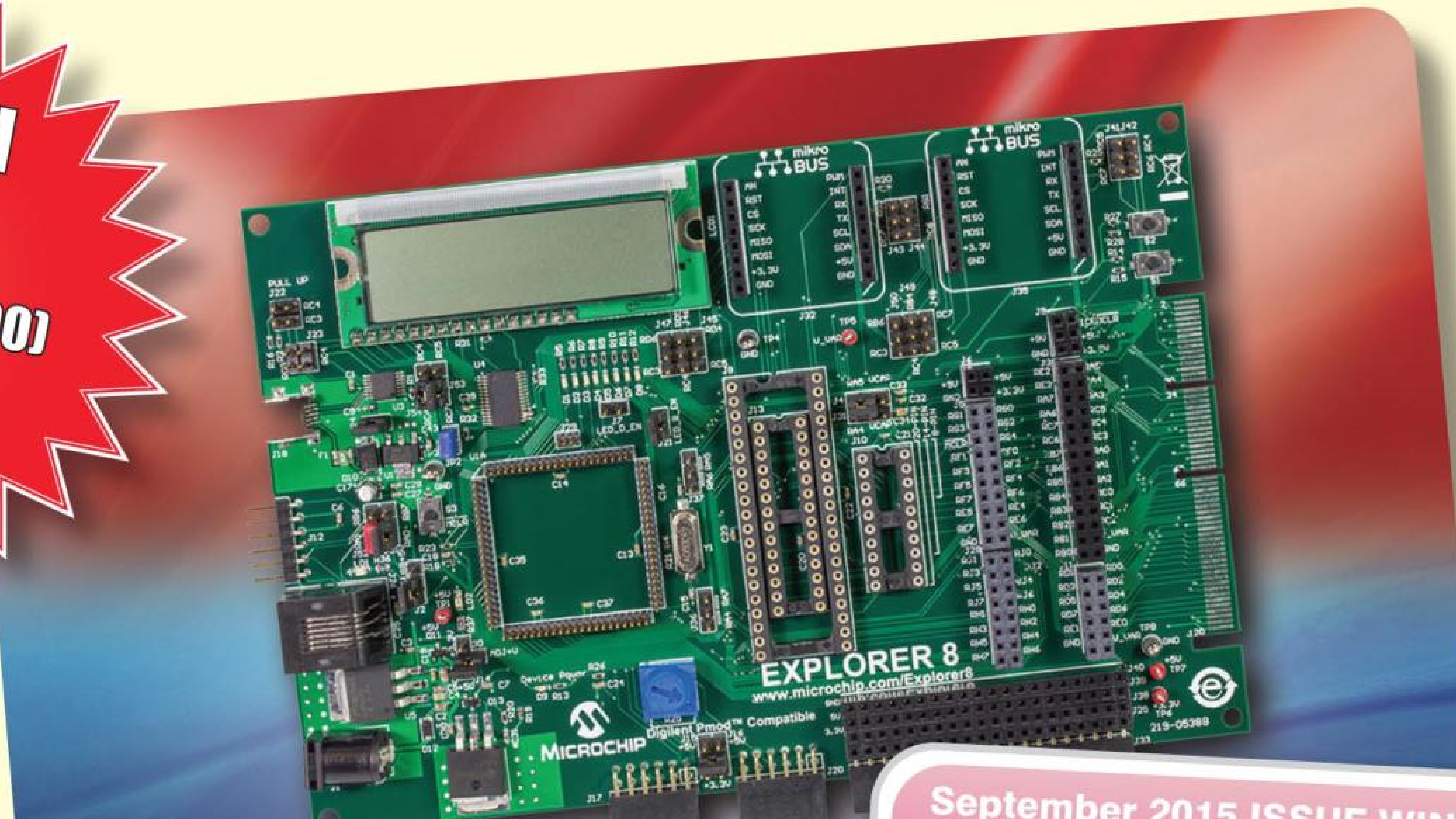

September 2015 ISSUE WINNER
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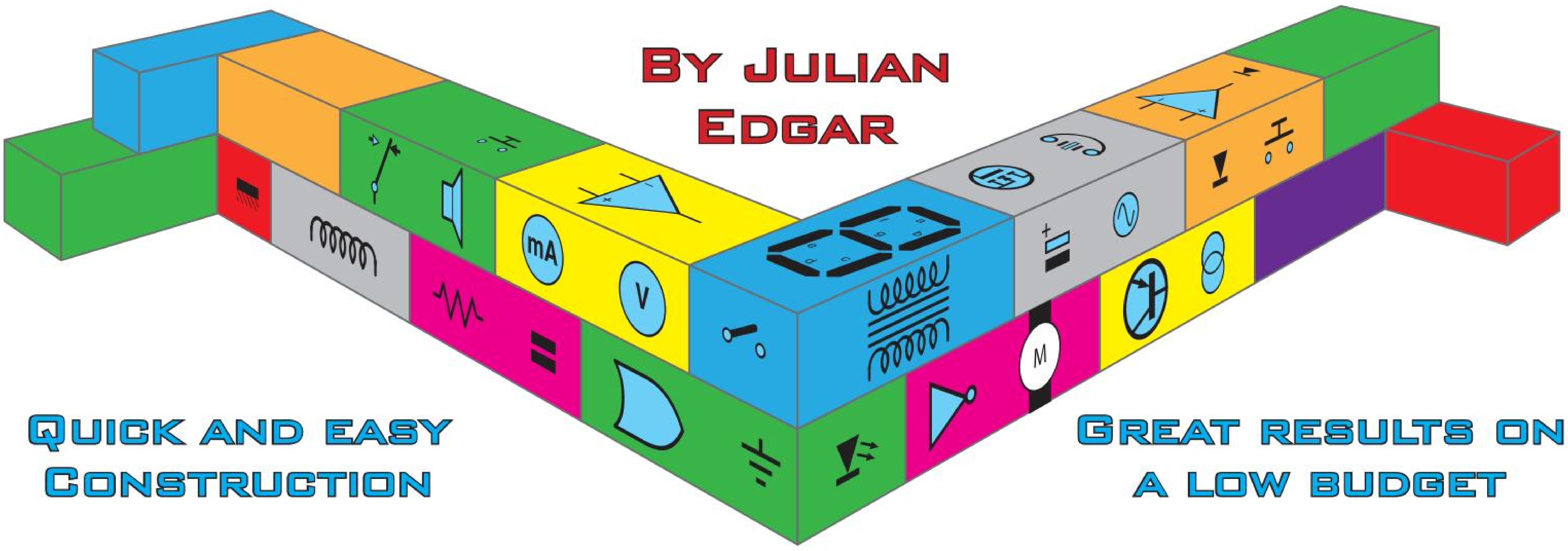
ELECTRONIC BUILDING BLOCKS



BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

GREAT RESULTS ON A LOW BUDGET

BUDGET VOLTAGE SWITCH

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Budget voltage switch

Here is an amazingly cheap voltage switch that activates a relay when the input voltage reaches the required level. Switching in response to a signal is a simple, but incredibly useful electronic function we all need to implement on a regular basis – use this quick and easy route with minimal fuss.

The switch is usually available through eBay (do a search under 'DC 12V Dual Wire Actuation Type Photoswitch Sensor Relay Module' – but see the sourcing note below). The module should cost you less than £5 delivered to your UK letter box.

Overview

So what do you get in the post? As described above, the device is sold as a photo-switch – it switches a relay on the basis of different light levels. The module comes with a light sensor that can be easily remote mounted. In fact, it's a perfect module for switching on lights when it gets dark.

But hold on, what's this got to do with a voltage switch? The trick is this: if you unplug the light sensor and instead feed a variable voltage to one of the exposed pins, the module then becomes a universal voltage switch, suitable for monitoring voltages in the range of about 0.5 – 5V. The module is powered by 12V.

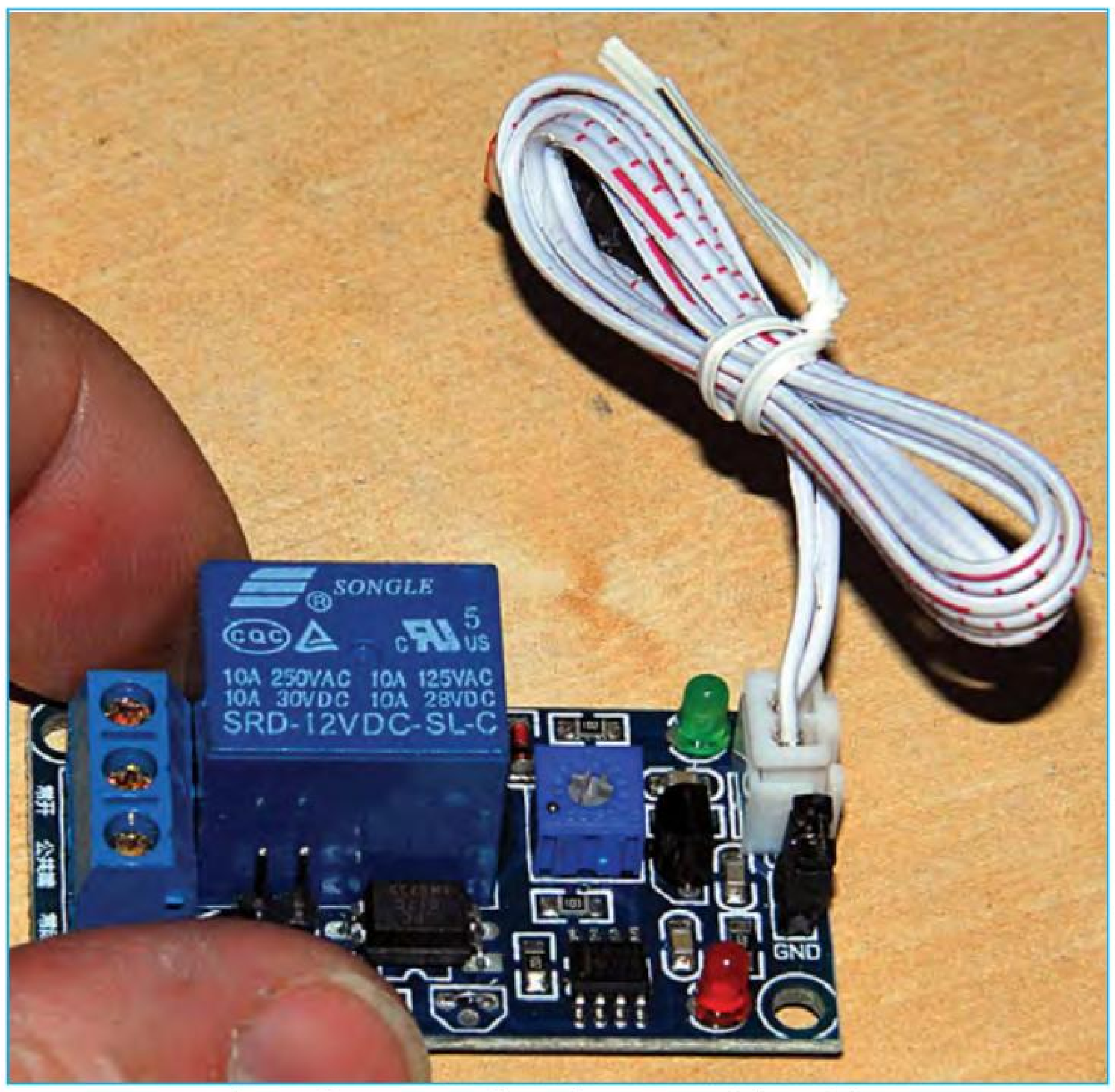


Fig.1. The voltage switch – cheap, useful and fun to use

Testing

We suggest that you first test the module as a light switch – just to make sure everything is working as it should. Fig.1 shows the module as it comes from the supplier.

First off, remove the link (arrowed in Fig.2) and place it in a secure place – it's easy to lose it.

Next, connect +12V and ground wires (Fig.3). Switch on power and the red LED should light, indicating that the module is powered-up.

Now shade the light sensor and the green LED (arrowed in Fig.4) should light and the relay click. Adjust the pot and you will be able to adjust the light level at which the relay operates.

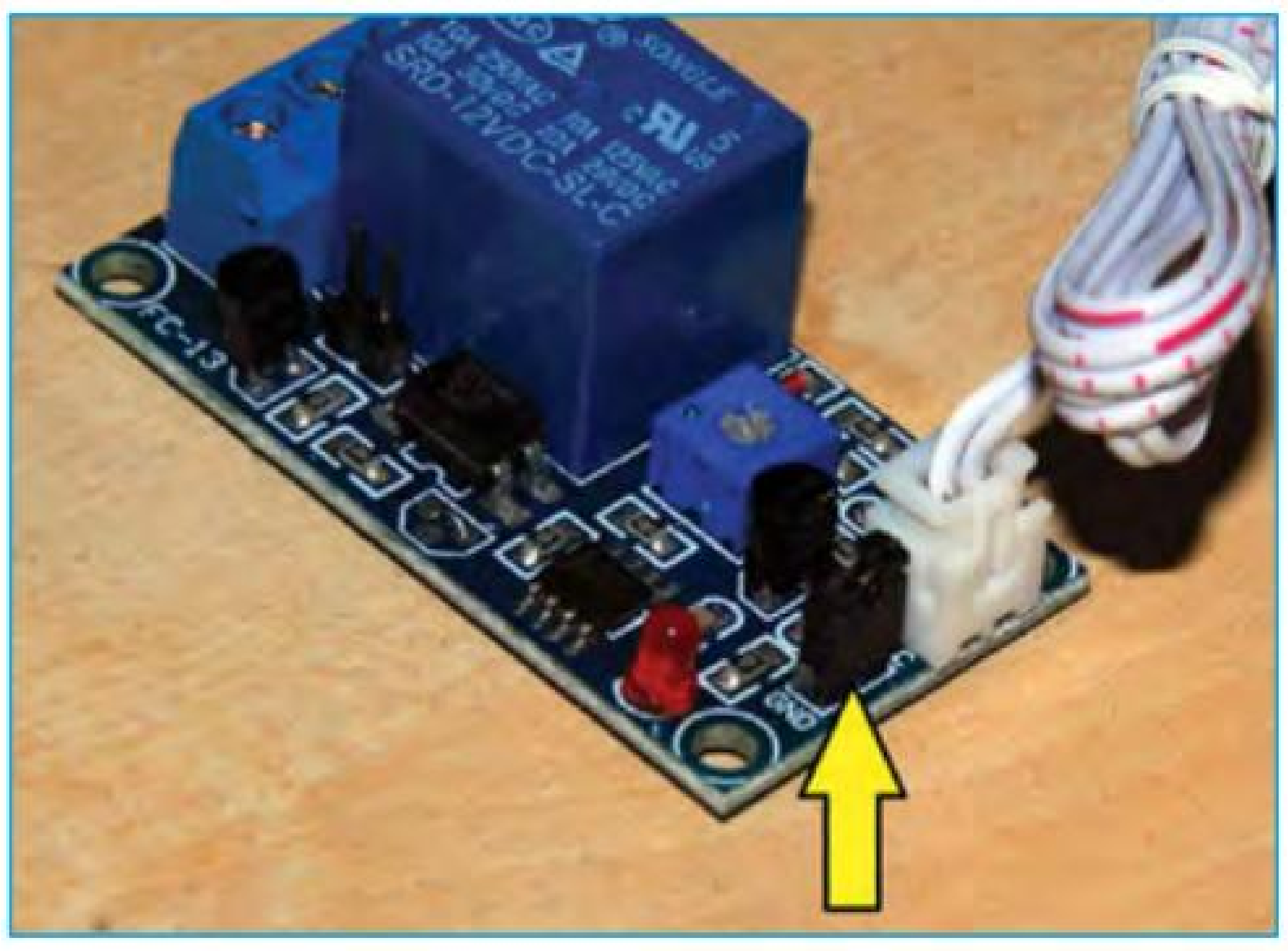


Fig.2. First remove the supplied link

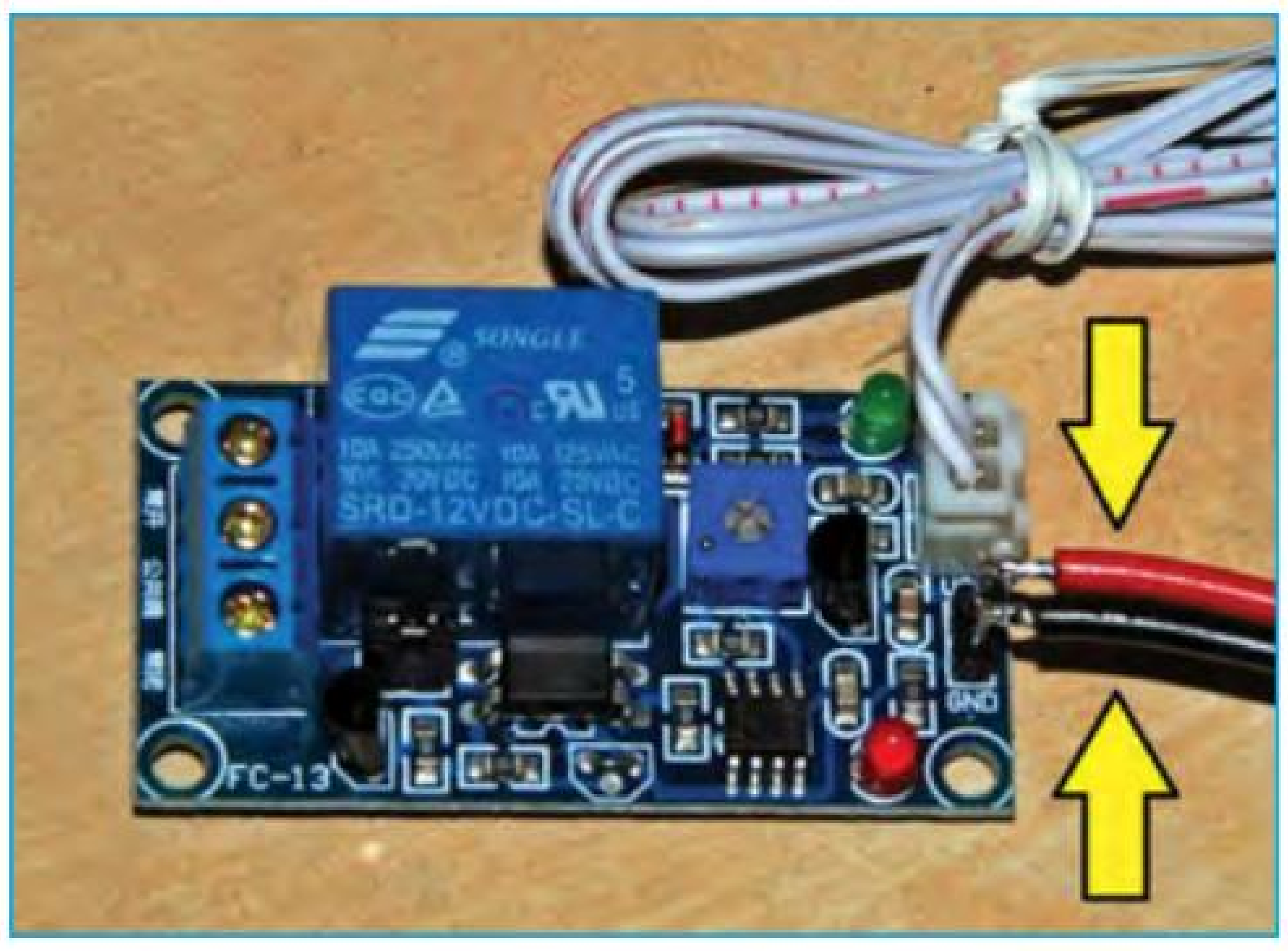


Fig.3. Power supply connections

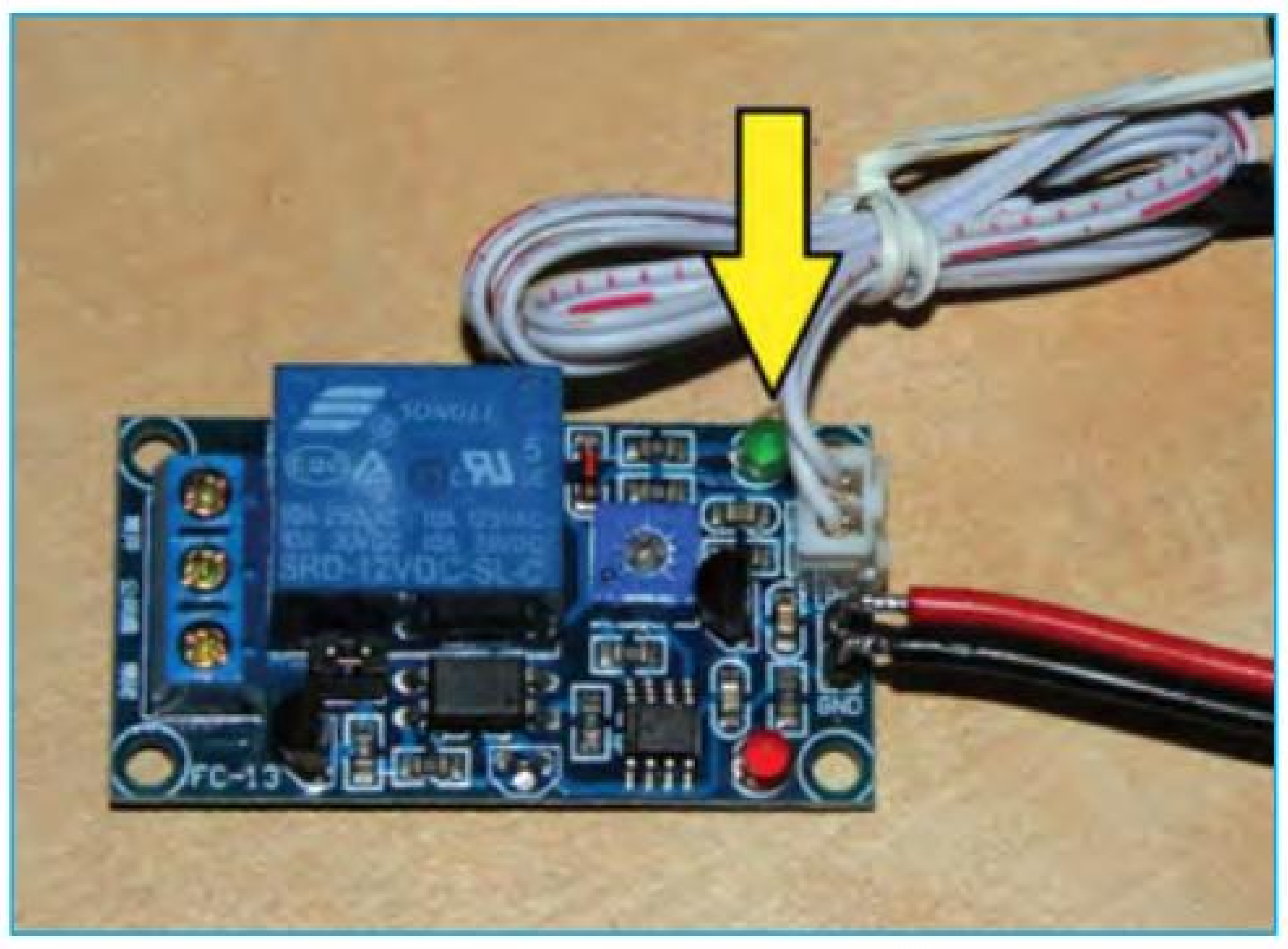


Fig.4. Green indicator LED

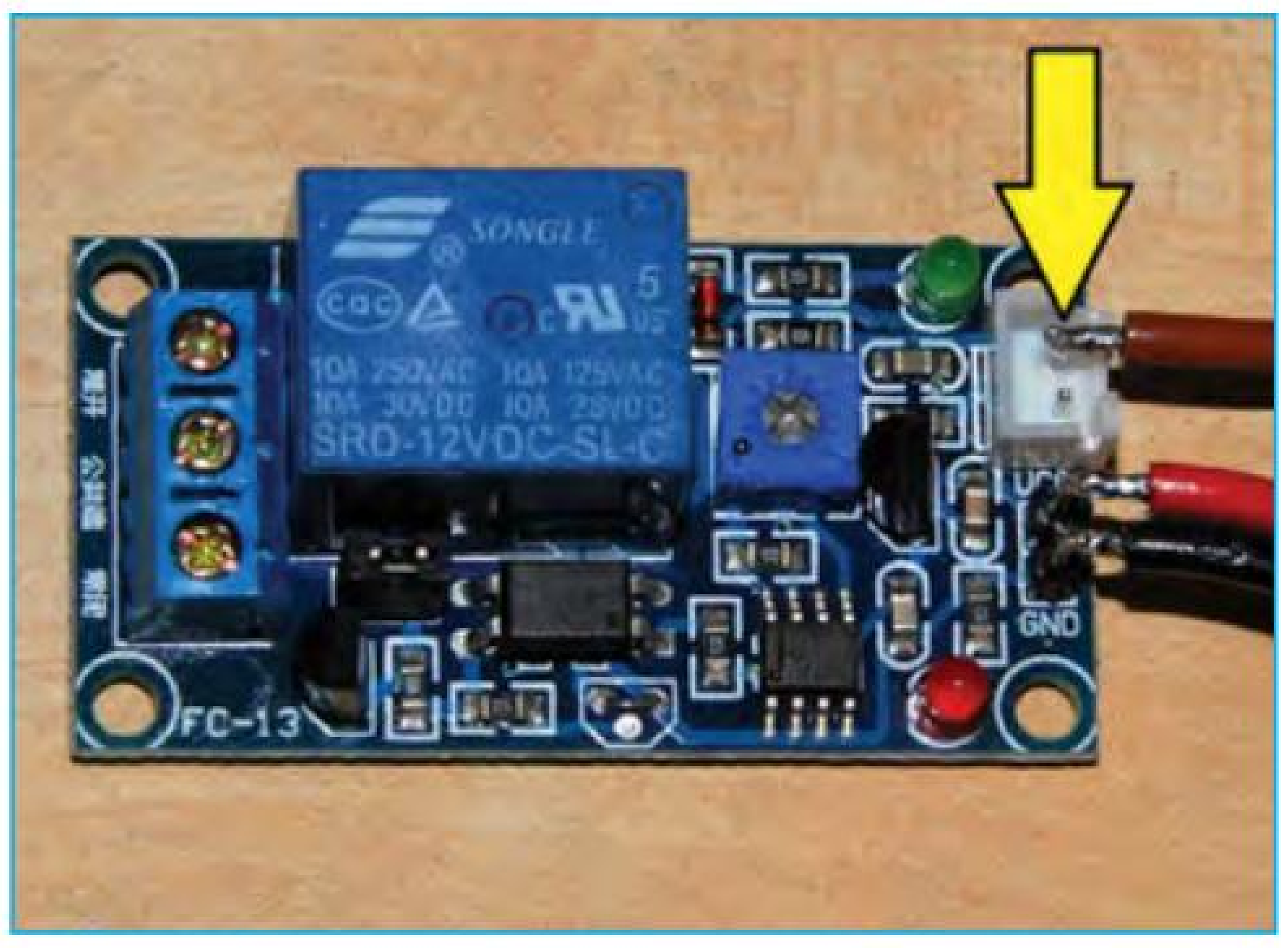


Fig.5. Signal input connection

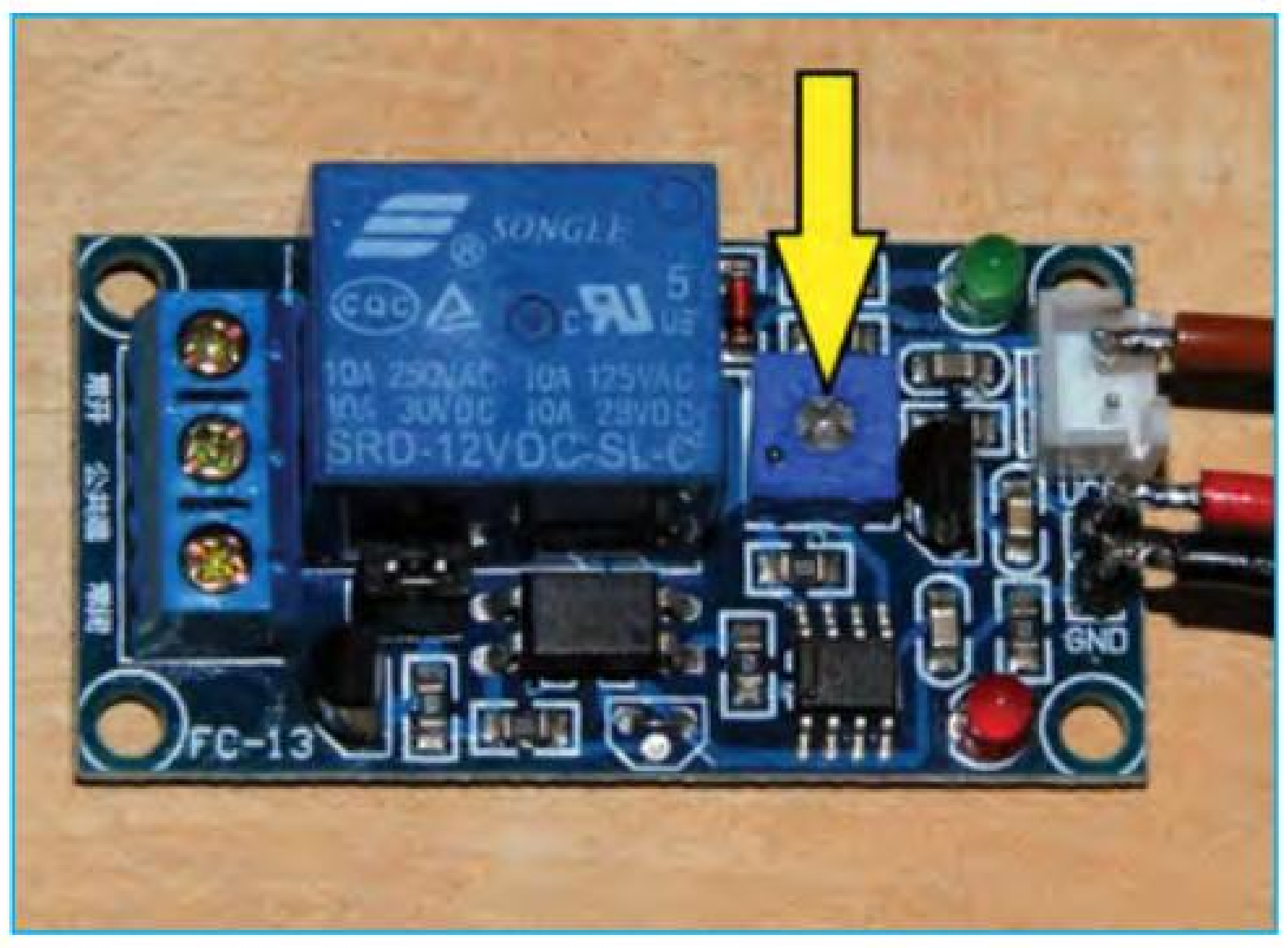


Fig.6. Use this pot to set the switching level

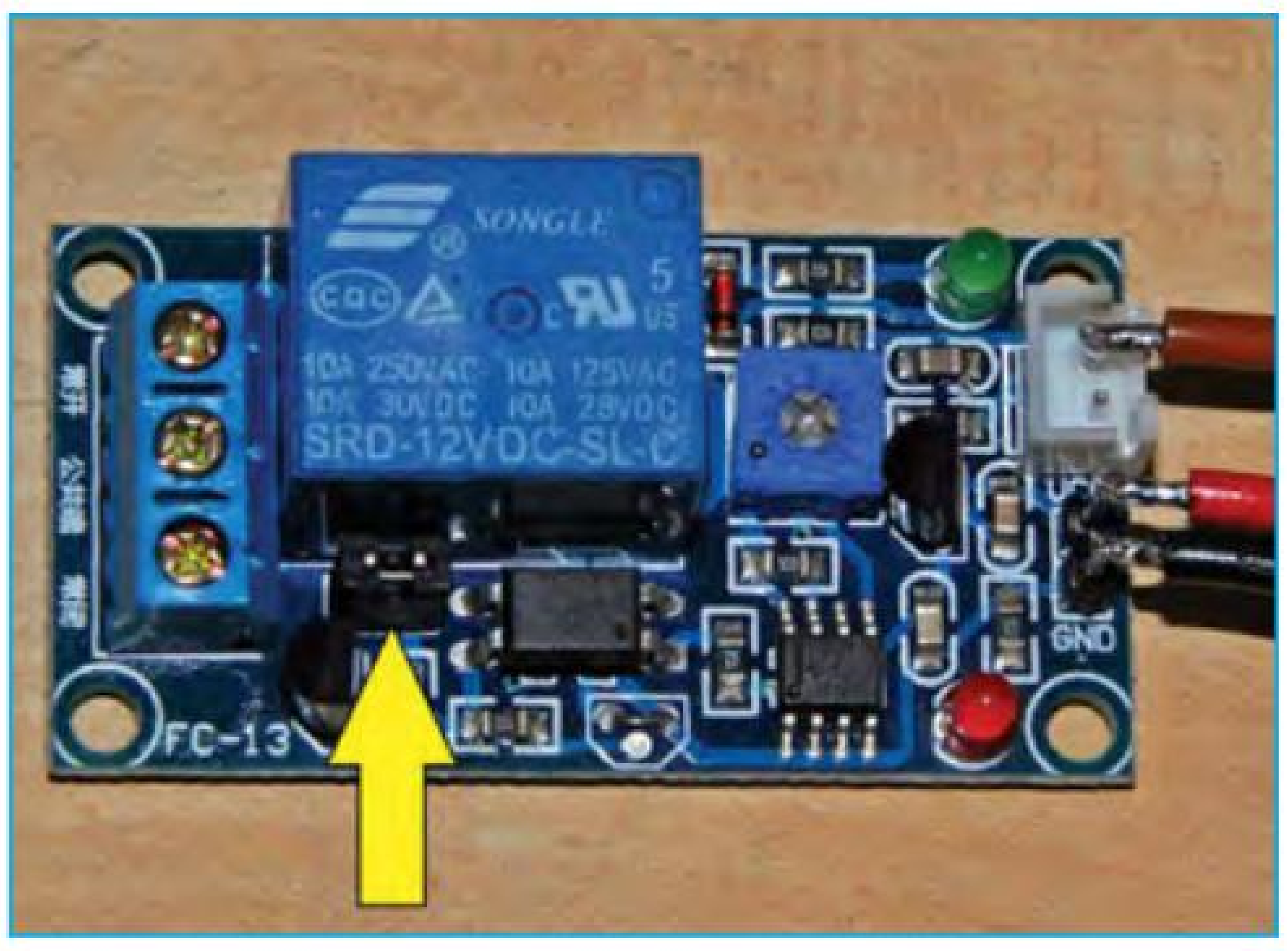


Fig.7. Set Common relay connection to 12V

Voltage switch

Carefully unplug the light sensor. Cut away part of the connector housing for the light sensor so that you can solder directly to the pins (Fig.5). Solder your input signal wire to the pin furthest from the power connections, as shown here by the arrowed brown wire. This is the wire that connects to whatever voltage source you are sensing.

Rotating the pot in Fig.6 anti-clockwise increases the voltage at which the module switches. When the pot is adjusted correctly for the application, a dab of varnish can be used to hold it in the chosen position.

The relay terminals are configured (from, top to bottom): Normally Open (NO), Common, Normally Closed (NC). If the link (Fig.7) is placed as arrowed (that's the link you put aside earlier), 12V is fed to the Common relay terminal. This makes wiring much simpler when you want to operate a low current load like a buzzer or lamp.

Fig.8 (top) shows the module configured to turn on a light when the monitored voltage exceeds the pre-set level. (Note the green LED is on). Fig 8 (bottom) shows the module configured to turn on a light when the monitored voltage is below the pre-set level. (Note how the green LED is now off.)

Conclusion

Cheap, simple and effective – that's our voltage switch!

Sourcing

We normally recommend eBay for this kind of device, but as luck would have it, just as we were going to press the original seller ran out of devices. The item was listing number 191589051309, and more may well be in stock by the time you read this. Have a search using 'DC 12V Dual Wire Actuation Type Photoswitch Sensor Relay Module'. A virtually identical part is listing number 291574999759. However, if eBay fails to provide the part do remember that a bit of Google research will show that there are plenty of other sources – for example: **http://tinyurl.com/pza9ypy**. Prices vary from under a fiver to a little over a tenner, so do shop around.

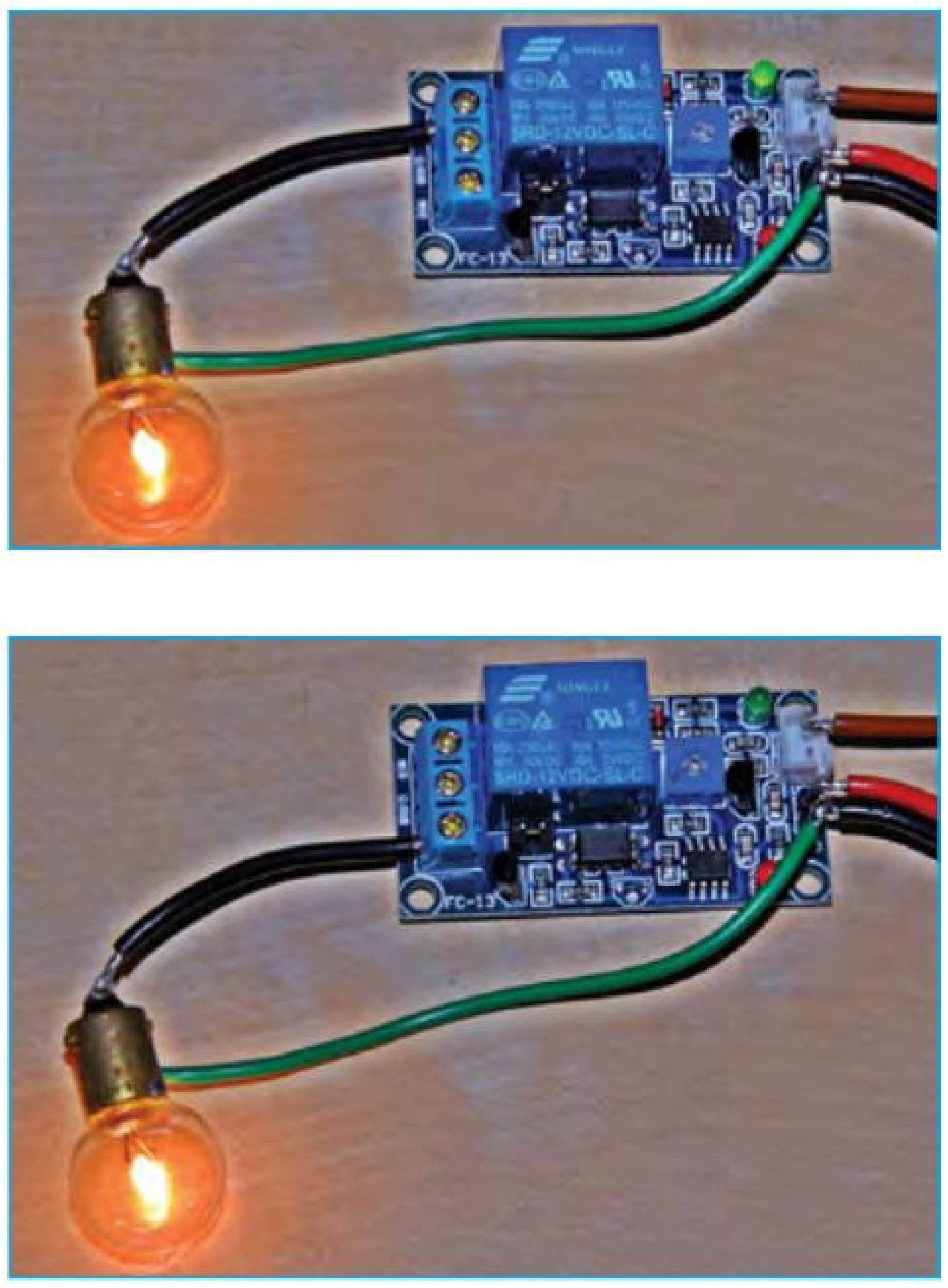


Fig.8. (top) Module turns light on for input above *pre-set level (bottom) or on for input* below *a pre-set level – note the green LED*

Next month

Next month, another great electronic module – one that can be used to pulse an output. It is widely adjustable, with both the 'on' and 'off' times able to be set separately. Better still, it uses a relay output that is able to drive high current loads (up to 10 amps). All this is in our next *Electronic Building Block* article.

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Next month – Pulsing Timer Module

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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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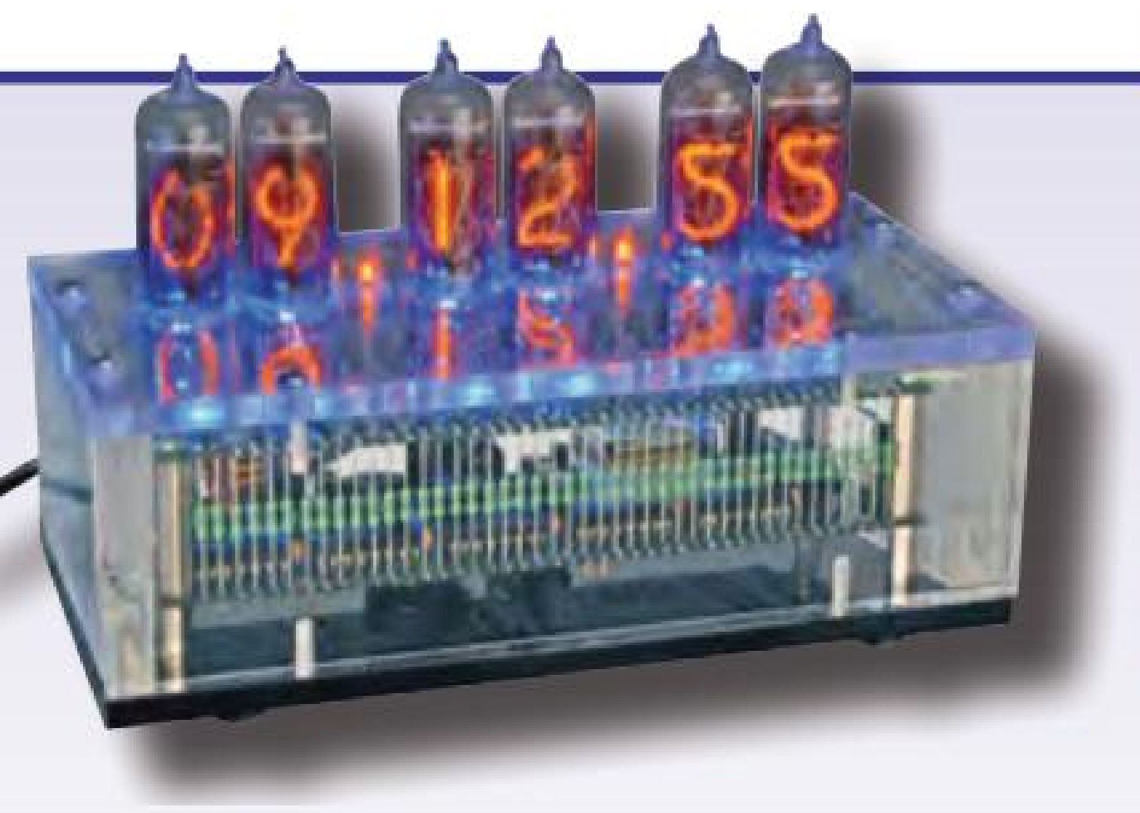

6-Digit Retro Nixie Clock – Part 1

Revel in the retro glow of this cool *Nixie Clock*! It may look like something out of the 1960s, but this is a modern design utilising a 32-bit microprocessor and (optionally) a GPS receiver module to always give you accurate time and date, automatically determined by your location. We've also added a date display function, a 7-day alarm and more!

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LoRa ™ Internet of Things

KCS has extended their successful TraceME product line with an advanced module, targeted for worldwide mobility in the Internet of Things era. The latest development of the TraceME GPS/GPRS Track and Trace module will combine the RF location based positioning solution with the LoRa™ technology. This combination offers 'smart objects' being even smarter, since LoRa™ enables long range, battery friendly communication in a wide variety of (M2M) applications. Supporting GPRS/SMS and optional 3G, Wi-Fi, Bluetooth LE, ANT/ANT+ and iBeacon™ provides easy integration with existing wireless networks and mobile apps. Other variants in the high/mid-range and budget-line will follow soon.

ANTI-THEFT module based on RF

KCS TraceME product line offers an intelligent location based positioning solution for indoor and anti-theft applications.The solution is based on RF with an intelligent algorithm of measuring the propagation time of transmitted (proprietary protocol) signals. Unique features are: minimum size (46x21x6.5mm), weight (7 grams for fully equipped PCB) and a standby battery lifespan of more than 10 years.'Listen before talk' algorithm makes it practically impossible to locate the module, which secures the valuable vehicle or asset. Supporting GPRS/SMS and optional 3G, Wi-Fi, Bluetooth LE, ANT/ANT+ and iBeacon provide easy integration with existing wireless networks and mobile apps.

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